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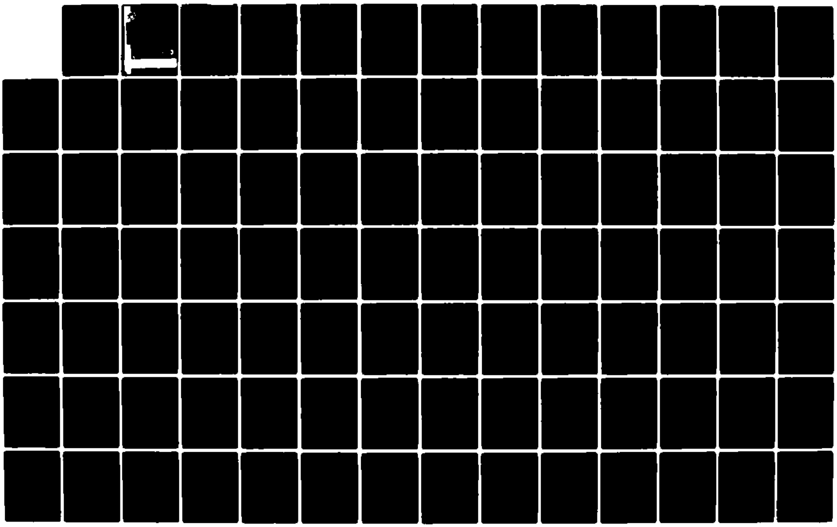

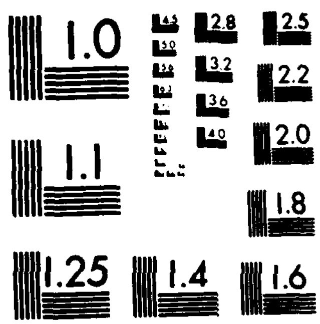

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VOICE TECHNOLOGY DESIGN GUIDES FOR NAVY TRAINING SYSTEMS

John C. Cotton
Michael E. McCauley

Canyon Research Group, Inc.
741 Lakefield Rd., Suite B
Westlake Village, CA 91361

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This project was directed toward gathering information about applications of automated speech technology (AST) and formulating design guidelines for the use of AST in Navy training systems. Information was obtained from three major sources: a review of the scientific and technical literature; a review of the documentation of prior Navy AST training system prototypes; and interviews with key scientists.

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Design guidelines for the design and development of AST training systems were presented in four categories: Voice Subsystems; Instructor Models; Simulation and Event Control; and Training System Executive. The design guidelines were generic and intended to be applicable to a wide range of training tasks.

Computer speech recognition and generation were characterized as rapidly advancing technologies that are ready now for application in automated training systems.

A human factors perspective was advanced by emphasizing the importance of the trainee in the design of complex automated training systems. Training effectiveness and user acceptance are objectives to be sought through careful design of the Voice Subsystem and supporting models and subsystems described in the report.

Both complex and simple applications of AST for training were addressed. The emphasis was on complex systems designed to reduce the need for instructors and other training support personnel. This reduction can be accomplished through speech interactive simulation and the automation of performance measurement, curriculum control, record keeping, and instructional presentation.

FOREWORD

This report is part of work done under Project 3753, Application of Voice Technology in Automated Systems. The objective was to develop techniques to augment training of personnel for jobs such as Air Intercept Controller.

Surface-based controller tasks require, in addition to an instructor, a keyset operator who functions as a "pseudo pilot" to maneuver the simulated aircraft in response to control commands from the student. The job is very boring and performance soon degrades. Further, training cannot be conducted during extended or after normal working hours due to nonavailability of keyset operators. Variance introduced by the use of human "simulator pilots" is so contaminating that proper training control and evaluation is extremely difficult. Integration of speech technology with automated adaptive training systems offers a potential solution to this problem by providing automation of "simulator pilots" capable of consistant performance with full time availability.

The application of computer speech recognition and generation is a rapidly-developing technology which is constantly being improved. This project has spawned the integration of this technology into three Navy prototype training systems: (1) an experimental Ground Controlled Approach (GCA) controller training system, (2) an Air Intercept Controller (AIC) controller training system, and (3) a Landing Signal Officer (LSO) training system (Project 7754).

Automated speech technology should also be readily transferable to other military and civilian applications. To facilitate the design of such systems, this phase of Project 3753 was aimed at generating guidelines for applications of speech technology in automated training systems. The design guides are primarily intended for instructional developers and training device design engineers who may be interested in the use of computer speech technology in their training systems. These guides should be considered tentative, however, until they are validated.

Joseph A. Puig
JOSEPH A. PUIG
Scientific Officer

PREFACE

This report describes the work performed under NAVTRAEQUIPCEN Contract N61339-80-C-0057. Dr. Robert Breaux served as the NAVTRAEQUIPCEN Project Engineer.

The authors would like to thank the key scientists who consented to be interviewed in the course of the project. In particular, Logicon, Inc. generously authorized interviews with personnel involved in the development of prototype training systems that included automated speech technology. Dr. Douglas C. Chatfield, President of Behavioral Evaluation and Training Systems (BETS), was invaluable as a consultant on the project. These individuals, however, should not be held responsible for the content of the report, which reflects solely the interpretations and opinions of the authors.

We appreciate the tireless work of Rosemary Wescott in the preparation and production of the report.

The design guides, found in Appendices A - D, were written by Mr. John Cotton. The body of the report was written by Dr. Michael E. McCauley. Any redundancy between these presentations was considered beneficial.

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SECTION I

INTRODUCTION

Speech interactive systems provide some direct benefits over more traditional man-computer interfaces such as the keyboard. Speech is a natural communication medium. It eliminates the requirement for naive or temporary users to be trained on keyboard functions. It can be particularly effective in a task situation charactertized as "hands-busy, eyes-busy." Speech does not compete directly with a visual-manual task; a keyboard does. A speech interactive system also can provide some mobility to the user, while keyboard/CRT interface fixes the user in one location.

In training applications, automated speech technology (AST) promises to reduce or eliminate instructor workload for verbal tasks, such as air traffic control (ATC). It promises to eliminate the need for instructional support personnel, such as pseudo-pilots, who listen to an ATC trainee's verbal transmissions and simulate the pilot response. These capabilities enable training to be automated, producing significant savings in personnel costs.

BACKGROUND

A series of research and development (R&D) programs within the Navy has been directed toward the development of experimental prototype training systems to investigate the feasibility and effectiveness of applying automated speech technology to training systems. Specifically, three R&D efforts are seeking to provide automated training for Precision Approach Radar Controllers (PAR), Air Intercept Controllers (AIC), and Landing Signal Officers (LSO). These systems are characterized by an automated adaptive syllabus, simulated instructor, simulated environmental events, automated performance measurement, and a strong voice interaction between the trainee and the system.

Both successes and difficulties have been encountered during these prototype and development programs. A need existed to review these prior developments and to produce guidelines for the future design of AST in Navy training systems. The purpose of the present study was to integrate current concepts in training technology with the lessons learned from these R&D programs in order to produce system design guides which will provide direction for the functional design of future AST training systems.

The design guides produced by this study will be directed toward training analysts, subject-matter-experts, and systems analysts to channel and facilitate their joint efforts in developing detailed functional specifications for their particular training application. Additionally, an evaluation plan will be generated to provide a mechanism for testing, evaluating and validating the experimental design guides.

SPEECH TECHNOLOGY EMPHASIS

The emphasis in this work has been on AST. This term is used to refer to both computer speech recognition and generation. The human-computer dialogue enabled by AST has the potential for revolutionizing the use of computers in society (see Evans, 1979; and Toffler, 1980). NAVTRAEQUIPCEN has been actively pursuing the practical applications of this technology through the development of prototype speech-interactive training systems. Like any new technology in its first applications, some shortcomings have been encountered in the prototype systems. One purpose of this report is to serve as the institutional memory of these shortcomings but, more importantly, to suggest ways to minimize the difficulties in future applications.

Although the emphasis of this study is AST, related topics are included, such as automated instructor models, simulation control, instructional systems development (ISD), and automated training system integration. A schematic diagram of the contents of this report is given in Figure 1.

The present study was directed specifically toward Navy training systems, but much of the information is applicable to other types of systems that include human-computer interaction via voice.

SCOPE OF THE DESIGN GUIDES

The design guides are intended as a primer on AST applications to training system design. They are aimed at experienced training system designers who are unfamiliar with the capabilities and limitations of this new technology.

The design guides are necessarily general, in order to be useful in a variety of training system applications. Specific examples of training systems are given to assist in conceptualizing applications issues.

The design guides are directed toward the FUNCTIONAL requirements of AST training systems. To go beyond functional requirements into engineering design specifications would be impossible within the framework of <u>generic</u> design guidelines. For this reason, and because the technology of computer speech recognition is evolving rapidly, manufacturer's names and product specifications are not included in the design guides.

Suggestions are given for how to use a speech interactive capability in complex, intermediate, and simple training systems. An example of a complex system is one that includes the following: real-time speech control in simulation (as in a ground-controlled approach); speech generation; automated instruction; automated performance measurement; and automated-adaptive curriculum control. The capabilities and limitations of AST must be considered in the design of all the automated subsystems in such a complex system. An example of an intermediate system is to replace an existing pseudo pilot with voice interactions between the trainee and a

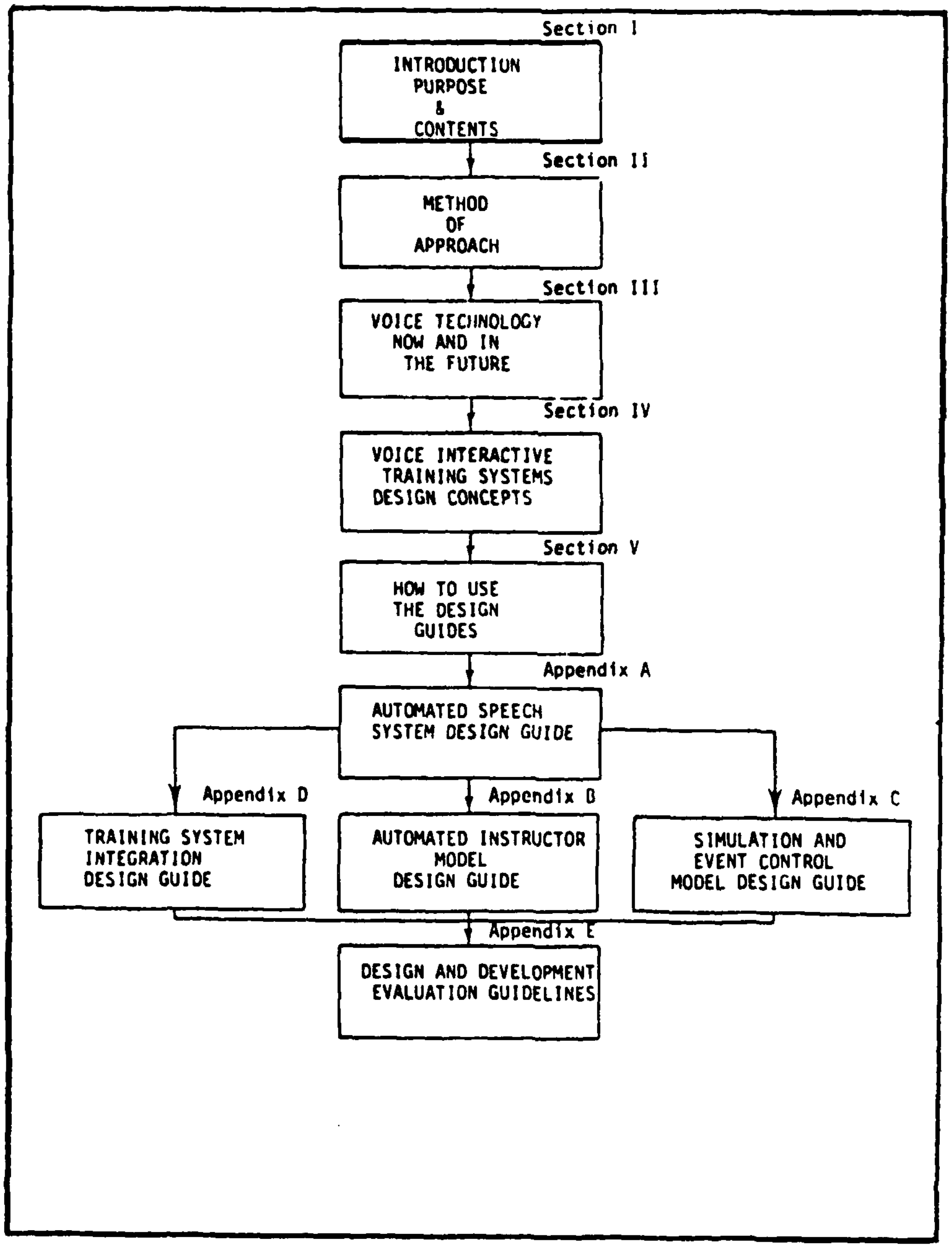

Figure 1. Voice Technology Final Report Layout

pilot/aircraft model, but to refrain from automating instructor functions. An example of a simple system is to replace a keyboard with voice-interaction in a computer-assisted instruction (CAI) system.

In addition to discussing various levels of complexity in AST training applications, the design guides suggest how to match speech system capabilities with training requirements, and, more generally, how to incorporate AST into the system development cycle. The benefit from the design guides herein will continue to occur up to the point when the system engineers write the detailed specification for a training system.

A brief overview is given of the current and projected capabilities of speech technology, but, the design guides focus on the principles of application of AST to training systems, rather than on a detailed technology review.

SECTION II

METHODS

SUMMARY

The methods of gathering information in support of the design guide development included: 1) Navy AST training system document review; 2) observation of Navy AST applications; 3) literature search and review; and 4) interviews with key scientists. Using these methods, information was obtained on:

- o Computer speech recognition technology
- o Computer speech generation technology
- o Navy AST training systems
  - Precision Approach Radar Training System
  - Air Intercept Controller Training System
  - Landing Signal Officer Training System
- o Automated training systems design
- o Instructor modeling
- o Automated performance measurement
- o Artificial intelligence (AI) and AST
- o Other Navy, Air Force and FAA applications of AST

The information was collated, organized and analyzed for applicability to AST training system development. The project Interim Report and Interim Meeting provided a forum for information presentation and feedback from NAVTRAEQUIPCEN. In response to the feedback, subsequent work broadened to include AST applications other than complex, totally automated training systems. Nevertheless, the focus remained on the integration of AST with other advanced training concepts, such as automated instructor and trainee models in a real-time, voice interactive simulation.

NAVY PROTOTYPE AST TRAINING SYSTEM DOCUMENT REVIEW

An important source of information for the project was the set of technical reports which document the development and use of AST in Navy prototype training systems, specifically, the Precision Approach Radar Training System (PARTS; also known as the Ground Controlled Approach Controller Training System, GCA-CTS), the Prototype Automated Controller

Training System for Air Intercept Controllers (PACTS-AIC; also known as Air Controller Exerciser, ACE), and the Landing Signal Officer Training System (LSOTS).

The documentation of these systems is available in NAVTRAEQUIPCEN technical reports. A listing of the reports obtained and reviewed during this project is given in the Bibliography. A substantial amount of the documentation was not directly applicable to the present study because it contained extensive description of system software. The most valuable information for the present project was obtained from the reports dealing with behavioral objectives, functional requirements, training characteristics, functional design, and training effectiveness.

OBSERVATION OF NAVY AST TRAINING SYSTEMS

Both PARTS and ACE have been observed directly by Canyon personnel during test conditions with actual Navy trainees. These observations occurred at the Navy Air Traffic Control School in Memphis, TN, and at the Fleet Combat Training Center Pacific, in San Diego, CA. These observations occurred during training effectiveness evaluations conducted by Canyon Research Group, Inc. for NAVTRAEQUIPCEN. (McCauley and Semple, 1980; McCauley, Root, and Muckler, in press) The "hands on" experience provided substantial insight into the strengths and weaknesses of these early efforts to develop a fully automated training system around speech technology.

LITERATURE SEARCH AND REVIEW

A literature search was performed to identify articles relevant to the project. The Lockheed Dialog system was used for the automated literatuare search. Six data bases were searched, using combinations of the key words "comnuter/automated, speech/voice/language, recognition/understanding/synthesis/generation/technology, interactive training/instruction system." A total of 224 citations was screened by titles and approximately 30 were obtained and reviewed. Additionally, secondary references and a "manual" literature search netted approximately 30 more pertinent articles and reports. These citations were listed exhaustively in the Interim Report for this project.

Many of the references obtained and reviewed during the project are cited in the Bibliography. It represents a relatively comprehensive compilation of the scientific and technical literature pertaining to AST and its application to training systems, as of 1981.

INTERVIEWS WITH KEY SCIENTISTS

Interviews were conducted with key scientists involved in research and development of AST applications. Most of the interviews followed a structured outline and were done in-person. Some less extensive interviews were done by telephone.

The interviews supplemented the information obtained from the training system documentation and literature reviews. A list of the people interviewed follows:

NAME	ORGANIZATION
M. Grady	Logicon, Inc.
M. Hicklin	Logicon, Inc.
E. Butler	Logicon, Inc.
R. Halley	Logicon, Inc.
G. Slemon	Logicon, Inc.
D. Chatfield	Behavioral Evaluation and Training Systems, Inc.
R. Lynchard	Eagle Technology, Inc.
C. Coler	NASA
D. Connolly	FAA
D. Lambert	NOSC
G. Poock	NPG School
M. Strieb	Analytics, Inc.
E. Werkowitz	USAF FIGR

Telephone interviews were obtained with:

A. Craft	U.S. Postal Service
G. White	Threshold Technology, Inc.
J. Welch	Threshold Technology, Inc.

The key scientist interviews proved to be a rich source of information on AST applications. Each application has a unique set of problems to be solved. A wide range of performance was obtained from the various speech recognizer applications. The information obtained through the interviews indicated a number of variables that influence speech recognition performance, such as speaker characteristics, noise environment, speech sampling procedures, vocabulary characteristics, and the degree of stress on the user. The interviews were valuable in identifying problem areas rather than solving the problems.

SECTION III

SPEECH TECHNOLOGY, NOW AND IN THE FUTURE

A brief overview of AST will be given, emphasizing its present capabilities and limitations. The overview will be followed by discussions of AST applications to training systems in Sections IV and V.

A comprehensive review of the history of automated speech recognition is beyond the scope of this report. Reviews and historical perspectives are available in Breaux, Curran, and Huff, (1978), Dixon and Martin, (1979), Hill, (1971), Lea, (1980), Lindgren, (1965), Martin (1977), and Reddy, (1976).

Likewise, discussion of the machine processes, algorithms, and strategies for recognizing speech are beyond the scope of the present report. Collections of articles on these topics can be found in Dixon and Martin, (1979) and Lea (1980).

SPEECH RECOGNITION AND UNDERSTANDING

Automated speech recognition, according to Lea (1980, p. 39), has a thirty year history "speckled with limited successes and repetitive discoveries of old ideas, and yet with a growing ability to successfully handle small vocabularies of words spoken in isolation."

In the 1930s and 1940s the evolving technology of radio gave rise to the sound spectrograph, a visual depiction of the acoustical energy associated with speech. The parameters associated with the spectrogram, energy by frequency by time, became the building blocks for subsequent efforts at automated speech recognition. In the 1950s researchers at the Bell Telephone Laboratories developed a system that successfully "recognized" a limited number of stored word patterns spoken by a single speaker (Dudley and Belashek, 1958).

The availability of the computer led to advances in speech recognition in the early 1960s. Time normalization techniques compensated for variability in word duration. Small, portable, inexpensive recognizers were developed that could accommodate a limited vocabulary size. Various strategies for enhancing recognition accuracy were attempted, based on principles of linguistics and auditory perception, as well as acoustic pattern recognition.

By 1968, a system was developed that was capable of well over 90% accuracy, with a 54 word vocabulary (Bobrow and Klatt, 1968). A few years later, the first commercial speech recognizers appeared on the market.

A significant impetus was given to speech recognition research in 1972 when the Advanced Research Projects Agency (ARPA) sponsored a five year program called the Speech Understanding Research (SUR) project. The ARPA

SUR project funded five system builders to pursue the objective of developing the capability to understand connected speech from many speakers with a vocabulary of 1000 words. Klatt (1980) and other chapters in Lea (1980) provide a comprehensive review of the advances arising from the ARPA SUR project.

The late 1970's seemed to be characterized by continuing the advancements in connected speech recognition begun during the ARPA SUR project, a proliferation of commercial recognizers of more modest capabilities, and the development of prototype systems applications. In 1978 the first connected speech recognizer became available commercially.

The present project is based on the prototype training systems applications of speech recognition technology. These programs, sponsored by NAVTRAEQUIPCEN, were begun in 1973 with a study of the feasibility of using AST in an automated training system for ground controlled approach controllers (Fuege, Charles, and Miller, 1974).

AST TERMINOLOGY

Like any new field of endeavor, speech technology has a new set of terms, or, more specifically, new connotations for old terms. The field of AST is an interdisciplinary one, being derived largely from acoustics, linguistics, and computing. The psychologist (human factors engineer) also is involved because of his focus on human-computer interaction, and the human element in systems design. The terminology in AST stems from all of these roots.

Recognition Versus Generation. Speech recognition and generation are the complementary functions of AST. Speech generation also is referred to as synthesis. The two major techniques for producing speech by machine are (1) to record, digitize and playback an actual human voice, or (2) to concatenate and synthesize speech from a set of machine-generated phonemes or words. Digitized speech is very "normal" sounding, but it requires that each word or phrase be pre-recorded. Speech synthesizers, on the other hand, tend to sound unnatural but require no pre-recording. Instead of pre-recording, a short program is written to select sequences of sounds that approximate the desired words. Summaries of speech generation technology have given recently by Kaplan (1980) and Michaelis and Wiggins (1981).

Speech recognition and speech generation allow the communication to flow both directions across the man-computer interface. The Navy's prototype training systems (PARTS and ACE) probably will be forerunners of a plethora of man-computer systems in the next decade that are designed around a speech interface.

Computer speech recognition is enormously more difficult than speech generation. Therefore, a heavy emphasis in this report will be placed on recognition. Speech generation will be given relatively short shift.

Recognition Versus Understanding. The term "recognition" often is used in the AST community to refer to the output of a commercial speech recognizer. This output is based, in virtually all present systems, on principles of acoustic pattern matching. The term "understanding" often is used to refer to supporting software that assists the recognizer by processing "knowledge" about syntactic, semantic and pragmatic information (see Lea, 1980). The "understanding" software enhances recognition accuracy by adjusting the probabilities of vocabulary items as a function of the syntactical rules of the language and "knowledge" of the task at hand. The understanding software can be considered a special case of artifical intelligence (AI) that uses all available sources of information to aid in correctly understanding the intended meaning.

Sometimes the term "understanding" software is used to imply the initial selection of automated responses to the recognized input. This use of the term strongly supports the contention that the understanding software is a type of AI. The response selection function of "understanding" software makes it analogous to human decision making and cognition, as studied by psychologists and modeled by AI specialists (see Barr and Fiegenbaum, 1979).

Isolated Word Versus Connected Speech. Isolated word recognition (IWR) refers to recognition systems that are constrained to deal with vocabulary items separated by pauses. This type of speech technology is also known as isolated phrase recognition (IPR), since any string of uninterrupted acoustic input less then some maximum time (typically 1 to 3 seconds) is processed as a single unit. The unit may consist of a single word, such as "continue," several words, such as "turn right" or a series of words, such as "this is your final controller how do you hear me". Each of these could be defined for the IWR system as a single unit of speech, i.e., an utterance.

Recognition systems with the capability to separate strings of input are called connected (or limited continuous) speech recognizers (CSR). These systems must segment the input string into its constituent units as well as recognize them. A considerable amount of higher level processing often is necessary to parse the input correctly. The most successful system from the ARPA SUR project, HARPY, for example, used syntactic knowledge, lexical knowledge, juncture rules, and phonemic knowledge to achieve good (>90%) recognition accuracy of connected speech (Lowerre and Reddy, 1980). It should be noted that for many practical applications requiring real-time speech interaction, large processing capacities are necessary to avoid the time constraints imposed by integrating these knowledge sources. Some of the difficulties associated with connected or continuous speech recognition were discussed by Levinson and Liberman (1981), who have been developing these techniques at Bell Labs for large and relatively unconstrained vocabularies.

For IWR systems the capacity requirements are less, but the user must separate the input string by pausing before and after each utterance. The implications of the pause requirements depend on the task. Where a

relatively naive user must input several strings of words/phrases within a perceived time limit, pauses are apt to be omitted, causing a reduction in recognition accuracy. The PARTS prototype trainer suffered some reduction in accuracy due to inexperienced users (precision approach radar trainees) failing to pause adequately between phrases (McCauley and Semple, 1980). The effect is likely to be most pronounced when the user tries to hurry because of task-related time requirements. However, recent advancements in the technology reportedly have reduced the pause time to less than 50 milliseconds. This capability diffuses the distinction between IWR and limited connected speech recognition.

The difficulties associated with machine segmentation of a digit string into individual digits were discussed by Flanagan, Levinson, Rabiner, and Rosenberg (1980). In some cases digit (word) boundaries may not exist because of coarticulation. For example, in the digit string "199," the final "n" in one becomes the initial "n" in nine, leaving no clear acoustical evidence for automatic segmentation into three digits.

Speaker Dependence Versus Independence. Most recognition systems today are speaker dependent. They sample the speech of the individual user to create a reference pattern, or template, for each vocabulary item. The number of samples for each vocabulary item varies from two to ten, depending on the manufacturer. This speech sampling process has been called various names, such as voice data collection (VDC), voice training, and enrollment. No matter what it is called, the process takes time. An extreme example would be a system which required 10 samples per vocabulary item. A moderate vocabulary size, such as 100 words/phrases, would require each user to produce 1000 speech samples before the system would be useable. Once a sample is taken, however, it may be valid for extended periods of time on some systems with experienced users. Poock (1981) reported good recognition accuracy with speech reference patterns sampled two years previously.

Speaker independent systems require no individualized speech reference patterns. Ideally, any person who speaks the language can use the system without prior speech samples. This type of system eliminates the time requirement for speech sampling, but it must be able to accommodate both the inter- and intra-speaker variabilities. This additional source of variability must be finessed by the use of "understanding" software, such as subsetting the vocabulary according to syntactical rules of the task/application (see Flanagan, et al., 1980, for an example).

HUMAN FACTORS ISSUES IN AST TRAINING SYSTEMS

High Expectations. Interacting with an automated system by voice is currently a novel experience for most people. Naive users are faced with uncertainties about what is expected of them, and what they should expect of the system. Although most manufacturers report 99% recognition accuracy, that figure usually is obtained under laboratory conditions by experienced speakers. A potential problem for AST acceptance is overly high expectations (Van Hemel, Van Hemel, King and Breaux, 1980). Despite

the impression given by science fiction movies, speech interactive systems presently are far from approaching the richness and complexity of human dialog.

Speech Sampling. IWR systems require the user to repeat each phrase from 2 to 10 times. In an automated training system, this procedure can be interleaved with instructional material to prevent tedious repetition (Hicklin, Barber, Bollenbacker, Grady, Harry, Meyn, and Slemon, 1980). However, at least one key scientist advocates successive sampling on each vocabulary item (Poock, 1981, personal communication). Poock suggests that phrase repetitions allow the user to introduce some variability into the sample, creating a reference pattern that is more "forgiving" of subsequent speech variability.

No matter what sampling procedure is used, trainees may find the process boring after the first few repetitions, as reported in the PARTS evaluation (McCauley and Semple, 1980).

A related issue is how to elicit speech samples. Visual prompts displayed on a CRT seem to be the most common method. Speech synthesis also can be used as a prompt, but this procedure sometimes induces unintentional mimicking of the synthesized speech characteristics (McCauley and Semple, 1980).

Context effects often are advocated for producing good speech samples. Context implies both physical and task context. For example, if the Precision Approach Radar trainee produces speech samples by reading from a list on a CRT, his speech pattern may be considerably different when controlling a simulated final approach.

Practice Effects. New users of AST vary in their obtained recognition accuracy. With the exception of the user who immediately achieves very high accuracy, practice and experience usually result in better recognition performance. This change probably occurs through increased voice control, leading to more consistent speech rate, inflection, and volume.

Increased voice control also is evidenced by the user's response to a recognition error. The normal reaction to a human recognition error is to speak more slowly, louder, and with more emphasis. This reaction may be effective for the human listener, but it is detrimental to automated recognition. The experienced AST user reacts to an error by repeating the phrase with aplomb, in the same manner he produced the original speech sample.

Recognition Test and Sample Updating

Most AST systems have a mode of operation designed to test recognition accuracy. The user speaks any of the trained vocabulary phrases, and the recognized phrase is displayed on a CRT, or otherwise fed-back to the user. The recognition test (or "speech test") mode is beneficial because it enables voice control practice, allows testing the limits of variability

tolerated by the system, and fosters the user's confidence in the system. Another important function of the recognition test mode is to determine whether the current set of speech samples is sufficient to achieve acceptable accuracy. For example, a fatigued user may suspect that recognition accuracy is declining during a long session. He can use the test mode to determine whether his suspicions are warranted. He then has the option to update the reference patterns of any word/phrases. This cycle of test-and-update can be used for any reason that would induce changes in the voice relative to the reference pattern (i.e., cold, flu, fatigue, smoking, etc.). Connolly (1979) addressed this issue in his studies on voice data entry in the Federal Aviation Administration.

Stylization. The speech stylization necessary for IWR systems is a definite constraint for some applications. It puts the burden on the user to modify a highly overlearned behavior (speech) to compensate for the lack of segmentation capability of the IWR system. Careful definition of the vocabulary items is essential to avoid unnatural pauses. But even then, some users may be expected to have difficulty inserting pauses correctly, and occasionally refraining from pausing between the words of a phrase unit. For example, in the PARTS vocabulary the following phrase would not be recognized if a pause were inserted, "This is your final controller, how do you hear me?" (Hicklin, et al., 1980). The trainees simply had to learn to refrain from pausing after the word "controller."

Speech stylization is not an important limitation in tasks with short, well defined command phrases. Many Navy training tasks would be in this category, including the GCA task trained by PARTS system. Speech tasks that involve lengthy phrases without explicit rules for pauses are more difficult for present speech recognition systems. Restructuring the vocabulary might be necessary before AST could be applied for training such a task.

Recognition Feedback. Feedback to the user is desirable in any AST application. It is particularly important in systems where a considerable probability of recognition error is experienced (i.e., greater than 5 or 10%). Feedback can be presented in several ways - alphanumeric readout on CRT, speech generation, or any unambiguous change in the visual or audio display. Without feedback, the trainee in a continuous task, such as an air controller, has no way to verify that his verbal information was recognized correctly. This places an additional burden on the trainee, to assess the situation, hypothesize whether his transmission was recognized correctly, then repeat it, modify it, or continue the problem.

The timing of feedback can be an important human factors issue. Normally, it should occur within a second or two from completion of the word/phrase. The exact time constraints are dependent on the temporal aspects of the task, especially the need for feedback before continuing to the next verbal transmission.

One difficulty with providing feedback to the user is to avoid interfering with the primary task. How to make the recognition feedback available to the trainee without being interruptive is an interesting system design issue. The answer clearly depends on the nature of the task and the changing demands on the trainees' attentional capacities (Chatfield, Klein, and Coons, 1981; Norman and Bobrow, 1976).

VARIABLES AFFECTING ACCURACY

Speaker Variables

A person's speech variability over time is the primary challenge for speaker-dependent systems. Speaker-independent systems are faced with the additional problem of variability between speakers. The human factors engineer and the systems designer should consider the potential avenues open to them for reducing the sources of variability that detract from AST system performance.

Between-speaker variability is largely beyond the control of the systems designer. Pre-testing or otherwise selecting the user population can be one tool for reducing between-speaker variability. Extensive speech training is another approach, but not a practical one for most applications. Some variables associated with between-speaker variability are:

- Sex (fundamental pitch)
- Speech rate
- Stress patterns (prosodics)
- Dialect

Speech recognizers have traditionally performed better with male speakers than female. According to Welch (1981, personal communication), this difference is greater in connected speech recognition systems than in IWR systems. Females, however, have obtained 99% recognition accuracy in a number of laboratory tests of recognizers (Doddington and Schalk, 1980), so it should not be concluded the AST is inappropriate for female users.

All of the characteristics of an individual's speech that make it unique, such as pitch, inflection, and stress patterns, make it difficult to design a speaker-independent recognition system. It must be immune to those individual differences, and be capable of recovering (or constructing) the invariants in the speech that correspond to the message.

Speaker-dependent systems attempt to account for intra-speaker variability through speech sampling, followed by acoustic pattern matching. One of the difficulties, however, is for the system to be flexible enough to accommodate a range of variability within the individual's speech, while maintaining an acceptably low proportion of false positive recognitions.

The variability (or lack of consistency) in the individual's speech, therefore, becomes an important factor that affects recognition accuracy in speaker-dependent systems.

Some of the myriad of variables that can affect an individuals consistency of speech are:

- o fatigue
- o evaluation stress
- o time stress
- o other task stress
- o health/medical
- o medication and drugs
- o affective state
- o general activity level
- o attitude/motivation
- o practice

Most current recognizers may be considered susceptible to errors when the consistency of speech changes due to any of these factors. Often the human listener is unable to detect subtle differences in the way a speaker says a phrase to the system, but the differences will be sufficient to change the outcome from a correct to an incorrect recognition.

Personal stress and tension may play an important role in recognition accuracy. Stress often will result in a pitch shift, an increased speech rate, and a tendency to omit pauses. These stress effects may be particularly important for training applications, where the trainee may be subject to a number of stressors, notably evaluation stress and time stress. The psychological aspects of time stress during training are discussed by Chatfield et al., (1981) who suggest that the time for cognitive processing is taxed during training.

Stress effects could be part of the explanation for the discrepancy between the mean recognition accuracy results of nearly 98% reported by Poock (1981) and 76% in PARTS (McCauley and Semple, 1980). Both these systems used essentially the same model of recognizer. Poock's graduate students were experienced in the task (a command and control computer net) and they were under no particular evaluation stress. The trainees in the PARTS evaluation were younger, learning the precision approach radar task, responding to an event-driven (time-critical) situation, and being evaluated after each trial. Each of these factors could be associated with increased stress. Poock (1981) noted that the average error rate increased in week 8 (of his 20 week study), which coincided with the school's examination schedule. He suggested that, "it is...a small indication of possible stress factors at work. It helps to point out that much remains to be done in the whole area of environmental and psychological stress effects on voice recognition performance" (Poock, 1981, p. 9).

Experienced speech system users commonly report 99% accuracy with a variety of systems (see Doddington and Schalk, 1980). The reason for the lower accuracy rates in many practical applications needs to be investigated. Slight improvements in recognition accuracy can mean large gains in system performance when an entire real-time, interactive simulation (and subsequent performance measurement) is being driven by the recognized speech input.

Environmental Variabilites

Environmental variabilities as well as speaker variabilities can contribute to recognition accuracy. Potential environmental factors are:

- o Ambient Noise
- o Vibration
- o Sustained Acceleration

Ambient noise can have a significant effect on accuracy, particularly when it varies between speech sampling and subsequent attempts at recognition. Coler (1980) has reported the detrimental effects of helicopter noise on recognition. But the use of a close-talking, noise-cancelling microphone and obtaining speech samples in the noisy environment can result in relatively good performance (Coler, Huff, Plummer, and Hitchcock, 1978; Coler, in press). The effects of noise on performance must be determined for each case because the interfering effects of the noise are a complex function of the overlap and temporal relationship between the noise spectrum and the speech spectrum.

The effects of vibration and sustained acceleration on speech recognition accuracy have not been studied systematically. Plans have been established to investigate acceleration (g load) effects on the centrifuge at the Naval Air Development Center, Warminster (Harris, in press). Vibration effects are certain to influence recognition accuracy within certain frequency and amplitude domains, but the authors are unaware of any studies on this issue.

Wind noise is another environmental variable that can potentially affect recognition performance. Wind protective devices are made for many microphones, but, again, the effects of wind and protection devices on computer speech recognition have not been systematically investigated.

In general, environmental factors can influence speech recognition at several points: within the human speech apparatus; at the microphone; and at the computer. Physical disturbance of the speaker, such as motion, vibration, or sustained acceleration, can produce a direct mechanical influence on his organs of speech production. Indirect effects can arise from environmental factors such as low humidity and dust that affect the vocal chords. In extreme temperatures, such as found in high altitude

flight, the effects might be most critical on the computer itself. Ruggedized components would be necessary to support automated speech technology in such hostile environments.

Vocabulary. Definition of the task vocabulary is an important part of achieving good recognition accuracy. In the general case, vocabulary size is related to accuracy. This is an intuitively appealing concept, because the probability of erroneously recognizing an utterance increases as the number of possible utterances increases. However, intuitively appealing concepts are not always correct, and at least one study has reported no significant relationship between vocabulary size and error rate. Poock (1981), using an IWR system, found no change in recognition error rate as the vocabulary size increased from 20 to 240 words.

The number of vocabulary items may be less important than the confusibility of the items. Probably the worst case for automated recognition is a vocabulary containing many single-syllable words. In the ACE system, for example, the words "Port" and "Four" are frequently confused (McCauley, Root, and Muckler, in press). Smith and Samber (1980) described the problem succinctly.

> As more words are added to the vocabulary, the more likely it is that words will be confused with one another. Sometimes this is because one word is a subpart of another, such as "Plea" being confused with "Please." Other times the confusion comes because words have similar acoustic descriptions...[and the] processors cannot distinguish between the acoustic patterns. An example of this is the words "What" and "Watt" (Smith and Samber, 1980, p. 151).

Vocabulary size and confusability must be weighed against the larger picture of the particular task or application. Imagine an hypothetical system where operational requirements would allow either "Nine" or "Niner" to be transmitted, i.e., it was not the case that only one of two was correct. The speech system designer could put both words in the vocabulary, and both would be recognized as "Nine." In this case, he did two things that are usually not good, but in this case, they improved the system: 1) He increased the vocabulary size, and 2) he allowed two words with potentially high confusability (because one is subset of the other). However, since both words are "mapped" to the same recognized output, the system is more flexible and "friendlier" to the user. It allows either word to be spoken, and, even if a confusion error is made, the final understanding is the same.

In summary, several vocabulary factors can affect recognition accuracy. These include the total vocabulary size, the number of short (one-syllable) words, and their acoustic similarity.

POTENTIAL APPLICATIONS

The potential applications of automated speech recognition are numerous, almost as unlimited as the use of speech itself. The commercial and military applications were outlined by Lea (1980), as follows:

Commercial Applications

- o Package sorting
- o Quality control and inspection
- o Programming numerically-controlled machines
- o Voice-actuated wheelchair
- o Banking transactions
- o Security and accesss control

Military Applications

- o Cartography
- o Training air traffic controllers
- o Cockpit control actuation
- o Spotting keywords in monitored conversations
- o Command and control

In another analysis of the AST marketplace, Nye (1980) noted that "the need is clear and the future bright for 'humanized' man/machine communications." He cited several types of present and potential applications of AST, including:

- o Data entry
- o Education and training
- o Medical
- o Inspection
- o Banking
- o Accounting
- o Computer I/O
- o Source Entry
- o Machine tool
- o Quality control
- o Material handling

Present limitations on AST applicability stem from several sources including cost, accuracy, speech stylization requirements, speech data collection, and vocabulary constraints. Despite some limitations, present recognition systems are sufficient to support many applications, such as command and control (Poock, 1980), data entry (Connolly, 1979), real-time computer interaction/simulation (Breaux and Goldstein, 1975; Grady and Hicklin, 1976, Halley, King, and Regelson, 1979), and non real-time interaction, such as Intelligent Computer Assisted Instruction (ICAI) (Meisel, in press). Many commercial uses of speech recognition are

possible, but information is available on only a few early attempts by organizations such as the U.S. Postal Service (Craft, 1981) and Lockheed (Lerman 1980).

The first commercial recognizer appeared in 1972. There currently are at least eight manufacturers of commercial speech recognizers (Nye, 1981). Their products range in price from less than $1,000 to nearly $100,000. The number of recognizers on the market has been increasing in the past few years. The price range also seems to be increasing because some manufacturers are seeking low cost, limited capability machines for the hobbyist, while others are reaching for the sophisticated realm of connected or continuous speech with large vocabularies.

Current advances in electronic chips are likely to reduce the cost while increasing the capability of available speech recognizers. The number of military and commercial applications can be expected to grow rapidly during the 1980s. Continuous speech understanding of large vocabularies may require years of research on syntactic and semantic processing, but automatic recognition of discrete words and phrases, with vocabulary sizes up to 1000 units, is a technology of today.

SECTION IV

REVIEW OF PRIOR NAVY AST TRAINING SYSTEMS

The Navy has sponsored the development of two experimental prototype training systems centered around automated speech recognition and generation. A third system is in the functional design stage. These prototype systems have contributed a great deal to the knowledge of the capabilities and limitations of current speech technology in support of automated training. The lessons learned from these prototype developments enable the potential of AST training systems to be assessed. Because these two systems represent the state-of-the-art, as of 1980-81, a brief review of each will be given. Examples from these systems then will be used repeatedly throughout this report.

PRECISION APPROACH RADAR TRAINING SYSTEM (PARTS)

Two names have been used to refer to the first application of AST to a real-world training problem - PARTS, and Ground Controlled Approach Controller Training System (GCA-CTS). This training system was developed by Logicon, Inc. under the sponsorship of NAVTRAEQUIPCEN during the time period of 1974 to 1979 (Fuege, et al., 1974; Breaux, 1976; Grady and Hicklin, 1976; Grady, Hicklin and Porter, 1980; Hicklin, Nowell and Petersen, 1978; Hicklin, et al., 1979a, Hicklin, et al., 1979b, Hicklin, et al., 1980). An independent evaluation of PARTS was conducted by Canyon Research Group, Inc. at the Navy Air Traffic Control School (McCauley and Semple, 1980).

The speech recognition technology incorporated in PARTS was a an IWR system, the Threshold 500, manufactured by Threshold Technology, Inc. and supported by "understanding" software developed by Logicon. A vocabulary of 107 phrases was used, varying in complexity from single digits to "This is your final controller how do you hear me?"

The speech generation technology included both digitized playback and a speech synthesizer by Votrax (Model VS 6.4).

The PARTS was a complex, sophisticated prototype training system. It included not just the real-time speech-interactive simulation of a PAR approach, but other advanced technologies such as automated instruction, automated performance measurement/evaluation, and automated syllabus control. A schematic diagram is shown in Figure 2. Detailed descriptions of the system can be found in Barber and Hicklin (1980) and Hicklin, et al. (1980).

In the future, it is likely that the PARTS/GCA-CTS development will be thought of as a pioneering effort that provided impetus toward the practical application of advanced, automated technology in support of instruction and training. It was not without shortcomings, however, as

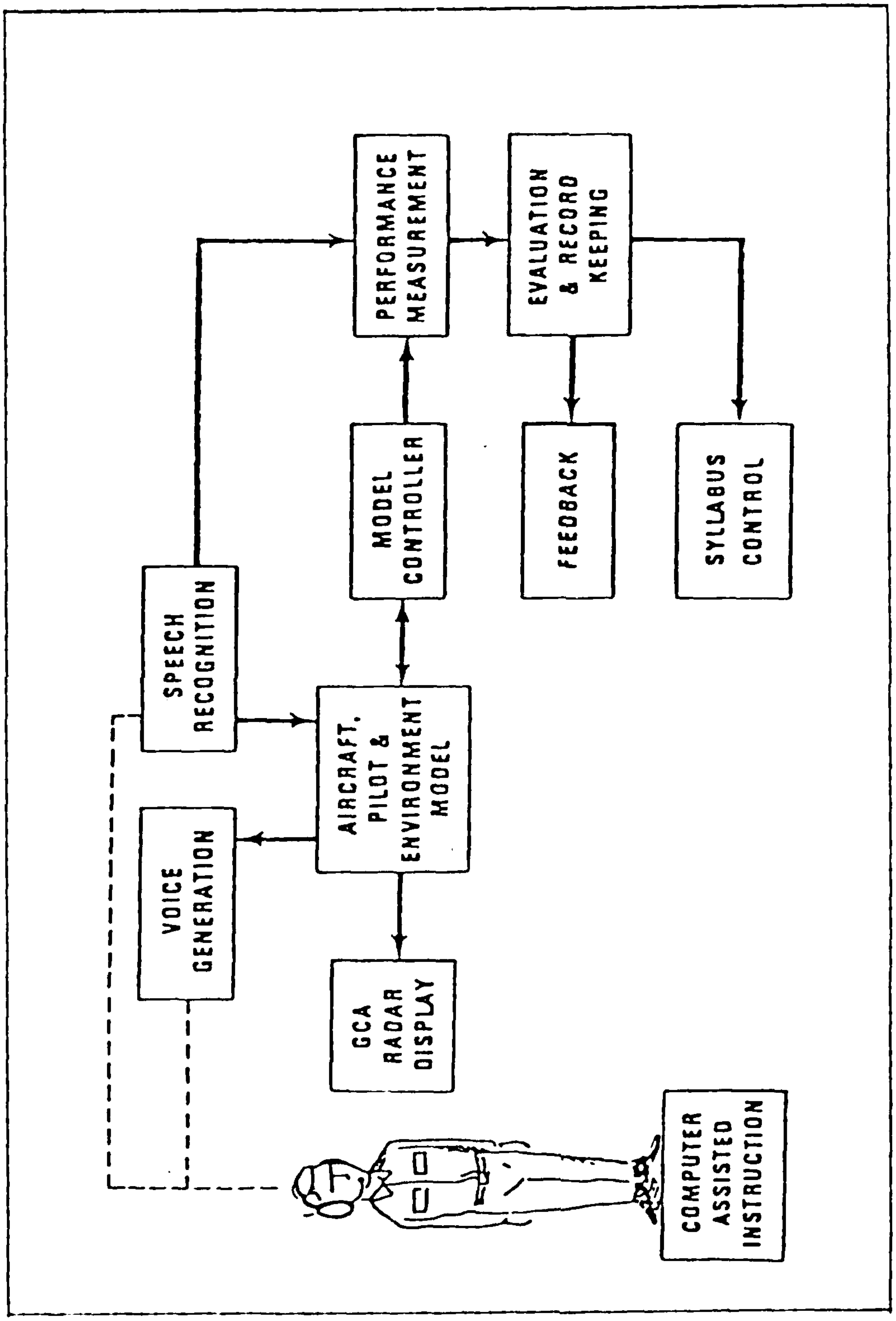

Figure 2. PARTS Training System Diagram (from Logicon, 1979)

might be expected in a prototype development of this magnitude. The evaluation of PARTS concluded that computer speech recognition is...

> sufficiently advanced to begin applying it in appropriate training tasks... From a training effectiveness perspective, the major problem encountered in PARTS speech recognition was the occurrence of a critical recognition error that sometimes caused loss of control of the [PAR] approach... Revision of the software supporting PARTS speech recognition would eliminate the problem of critical recognition errors. The [problem] serves to emphasize the importance of developing task-specific [understanding] software for each application of automated speech technology (McCauley and Semple, 1980, p. 119).

The evaluation recommended that the feasibility of applying AST to training should be studied on a wider basis for Navy air traffic controllers, including area surveillance radar (ASR), radar air traffic control facility (RATCF) and carrier air traffic control center (CATCC).

The difficulties encountered in PARTS speech recognition can be summarized by the average transmission recognition accuracy (TRA), which was 76% for the 22 students who completed the final performance test. The TRA measure underestimates word/phrase recognition accuracy because some transmissions consist of several words/phrases, such as "*Turn right heading 160, over.*" This transmission consisted of five items in the vocabulary, and would be said "Turn right heading PAUSE one PAUSE six PAUSE zero PAUSE over." A recognition error in one or more of the five items was scored as a transmission error. This measure might be judged as harsh by AST manufacturers, but in the PARTS task, the aircraft would not respond appropriately unless the entire transmission was "understood".

The difficulties arising from this mediocre recognition performance can be understood by reference to the previous figure showing the schematic diagram of PARTS. Speech recognition provides the input to the simulation (aircraft/pilot/environment model), performance measurement, and subsequently, evaluation and recordkeeping, feedback, and syllabus control. Any errors in speech recognition, therefore, cascaded throughout the remaining system functions. This is a knotty system design problem; one which will be discussed in more detail later in this report. Suffice to say that any improvements in speech recognition accuracy would have resulted in substantial gains in PARTS training effectiveness. Further development of syntactical and other "understanding" software may have produced such improvements (see Strieb and Dow, 1980).

Finally, it should be mentioned that the PARTS speech recognition system was dealing with a difficult situation because the users were students who were: 1) under learning stress; 2) under evaluation stress; 3) inexperienced in radio communication; and 4) only on the system for a short time (4 1/2 days). A recognition/understanding system more tolerant

of users who are inexperienced and stressed would produce an immediate leap in overall system effectiveness. Even using the original recognition system, increased recognition accuracy could be achieved through careful human factors integration of the speech capability into the overall system.

The effectiveness of the automated instruction, performance measurement, and syllabus control functions of PARTS was reduced by both speech recognition errors, as described above, and by design deficiencies, some of which may be unavoidable in prototype systems. These issues have been discussed by McCauley and Semple (1980) and will not be reiterated here. However, many of the lessons learned from the PARTS prototype are reflected in the design guides herein.

AIR CONTROLLER EXERCISER (ACE)

The ACE system has a lineage similar to PARTS. It has been known by another name, the Prototype Automated Controller Training System for Air Intercept Controllers (PACTS-AIC). It was developed by Logicon, inc. under sponsorship of NAVTRAEQUIPCEN during the time period of 1977 to 1981 (Anders, Grady, Nowell, and Overton, 1979; Clark, Halley, Regelson, Slemon, Van Steeg, et al., 1979; Grady, Hicklin, and Miller, 1977; Grady, Porter, Satzer, and Sprouse, 1979; Halley, Hooks, Lankford, and Nowell, 1979; Halley, King, and Regelson, 1979; and Smith, Granberry, Halley, Regelsen, and King, 1980). An independent evaluation of ACE is underway in 1981/82 at the Navy Fleet Combat Training Center Pacific.

ACE uses the most sophisticated connected-speech recognition (CSR) technology currently on the market, the NEC DP-100, manufactured by the Nippon Electric Company. Supporting software was developed by Logicon. The speech generation aspects of ACE include both computer synthesized speech (by VOTRAX) and digitized speech recording and playback.

ACE was designed to use the connected speech capability for digit strings in the AIC's vocabulary, such as giving aircraft headings, or bearing and range to a "bogey" (potential enemy) aircraft. For example, "Bogey two seven zero, twenty three" tells the pilot that the location of the bogey is bearing 270° at 23 miles. Updated bearings and ranges are given so frequently in this task that the requirement to pause between each digit would detract from the realistic pacing of the task. The CSR technology is better suited than IWR for the fast pace of the digit strings spoken by the AIC trainee. Other portions of the AIC's vocabulary tend to consist of short phrases, compatible with the pauses required by IWR technology. The connected speech capability of the NEC system allows concatenation of up to five words/phrases within a five-second interval.

The speech generation subsystem in ACE includes several current methods. Computer synthesized speech is used to simulate the messages from the pilot. Digitized speech is played back to simulate messages from a tactical controller, and the trainee's speech is recorded and digitized

to enable a training scenario to be replayed. The remaining audio capability is part of a video disc system, which includes both audio and video.

Although speech technology is the central research issue in ACE, several other emerging technologies also are included. Video disc is used for presenting instructional information and demonstrations. It provides rapid access to audio-visual materials and can display either still or moving video. Full simulation of the AIC operating environment is achieved through the use of pilot/aircraft models that interact in real-time with the trainee's verbal transmissions. The trainee's console is a simulated Navy Tactical Data System (NTDS) console with extra features, such as a CRT, to enhance training. Automated adaptive training is achieved by criteron-based assessment of trainee proficiency. Instructional sequence decisions range from remediation through rapid advancement by optional "challenge" opportunities. Records of trainee performance are kept by automated data-base management. Performance summaries are available for perusal by the instructor. Automation of the entire job of the human "pseudo-pilot" is enabled by the combination of computer speech recognition, synthesis, and pilot/aircraft modeling. Further reduction in the workload of instructional personnel is achieved by the automation of many of the tasks and functions of the instructor. Automated instruction, task simulation, performance measurement, syllabus control and record keeping combine to produce a nearly "instructorless" training system.

The evaluation of ACE is not completed at the time of this writing. However, early indications are that the capability of the connected speech recognition system to correctly recognize digit strings, e.g., "two seven zero twenty three," must be improved to achieve full system effectiveness (McCauley, Root, and Muckler, in Preparation). It is possible that improvement could be obtained by further development of the "understanding" software in support of the speech recognition device.

LANDING SIGNAL OFFICER TRAINING SYSTEM (LSOTS)

The LSOTS represents the third NAVTRAEQUIPCEN program to apply AST to training. This system is in the early development stages. Only the functional design and description of the instructor model and pilot/aircraft model have been developed (Hooks, Butler, Gullen, and Petersen, 1978; Hooks and McMurry; 1981; McCauley and Borden, in press; McCauley, Cotton and Hooks, in press). A preliminary test of the concept of real-time voice interaction between an LSO and a simulated pilot/aircraft during carrier approach led to mixed results (Hooks. Butler, Reiss, and Petersen, 1980).

Large challenges must be faced in the application of interactive speech technology to LSO training. The LSO's task in carrier approach involves a relatively short period of active control, approximately 30 seconds. LSO voice commands must be recognized quickly (less than one second) and accurately (approximately 99%) for the system to be effective. The high stress of the LSO task can be expected to induce speech

variability, including differences in speech volume and inflection, that will make automatic recognition difficult. Perhaps the saving factor is the relatively limited vocabulary, less than 70 phrases, that could suffice for an LSOTS. Recognition systems that are "tolerant" of stress-induced changes in speech will be needed to support the LSOTS application. The present authors do not subscribe to the argument that the speech recognition system can serve to screen stressed trainees from the training program. Achieving a degree of stress in the LSOTS would be evidence of both good simulation and a valid perception of the trainee that LSO errors can be costly and deadly. The measure of the LSO trainee must be that he performs his job well under stressful conditions; not that he feels no pressure.

While the LSOTS presents interesting challenges, it also epitomizes the potential benefits of AST in training systems. LSO training has long been accomplished strictly by on-the-job training. An "instructorless" LSOTS would enable concentrated learning experiences to be provided without placing a time burden on the (always overworked) experienced LSOs to support the training system.

SECTION V

VOICE INTERACTIVE TRAINING SYSTEM CONCEPTS

THE TRAINING SYSTEM DEVELOPMENT PROCESS

Automated speech technology can be integrated into a training system either as a retrofit to an existing trainer, or as an integral part of the original system design. This report emphasizes the latter application because it is more encompassing and more amenable to generic discussion.

Training system development should follow the general guidelines of the ISD process (Branson, Rayner, Cox, Furman, and King, 1975). Media selection is part of the ISD process, but at the present time, speech technology is not included in ISD documentation as a potential vehicle for information exchange in training.

Speech technology may be appropriate for a training system directed toward any Navy task that involves speech output. The analysis of the task should include thorough documentation of the task vocabulary, including the number of speakers, the size and content of the vocabulary, and the use of standarized vocabulary and common exceptions. This vocabulary analysis should become a routine addition to the task analysis of ISD.

When AST is considered for a training system, the analysis of the vocabulary, the task, and the training objectives, must be brought together into a top-level description of technological requirements. The state-of-the-art in AST is changing rapidly. Therefore, it should be reassessed for each training system to determine whether it matches the estimated system requirements.

This process involves a "top-down" analysis, beginning with the functional training requirements. Too often, a new technology is identified and "force fit" into a problem. Automated speech technology has very positive attributes, such as enabling real-time voice interactive simulation and automated scoring of speech tasks. It should be used, when appropriate, to replace training support personnel, such as pseudo-pilots or instructors. The decision to use AST should be based on cost effectiveness, training effectiveness and manpower availability.

The people involved in developing a complex AST training system should reflect at least three types of skills: 1) a training expert (instructional technologist, educational system specialist, or psychologist); 2) a systems engineer with experience in both hardware and software; and 3) a subject-matter-expert (SME) who has recent experience in both the operational task and in training the task. Another type of person who would be a valuable asset for AST training system development is one with background in speech recognition systems. Relatively few people fit in this category at present, and it should not be considered essential for such expertise to be represented on the design team. The other team

members will acquire speech system background during the project. They should be encouraged to facilitate this process by assimilating reviews, such as Dixon and Martin (1979) and Lea (1980), and by observing and using actual speech systems whenever possible.

As the design team acquires skill in using speech recognition systems, they should not forget that the recognition performance they experience will no longer be representative of that obtained by the naive user, such as a new trainee. It is a common tendency for system designers to lose perspective of the knowledge/skill differences between themselves and the eventual users. Any system seems easy to operate when one has "lived" with it for an extended time. The system must be designed for the eventual user, not for the design engineer (i.e., education, background, skills, experience, and other characteristics). While these issues may apply across a broad spectrum of systems, particular reference is made here to the common finding that experienced speech recognition system users obtain better recognition accuracy than naive users (cf. Armstrong and Poock, 1981).

Management of the system design team can play an important role in the characteristics of the final training system. Teamwork is essential. Overlapping areas of expertise and concomitant responsibility should be defined and discussed. Balance between the team members is essential to the efficient design of an effective training system. Intermittent contact with Navy operational personnel is not sufficient to design a good training system. Effective design of automated instruction is promoted by daily communication between the instructional specialist, the SME, and the hardware/software expert.

Developing a complex automated training system must be an iterative process. Each building block of the system must be developed, tested, evaluated and revised (TEAR) (see Figure 3). The building blocks may be hardware, firmware, software, or courseware. As they are integrated into increasingly larger configuration items during the system development, TEAR will be necesssary each step of the way. This concept is not saying anything new to system developers. But the time and resources often are not allocated for the TEAR cycle, particularly in the final stages of development, i.e., in-plant testing and on-site (field) testing. Insufficient time and resources to accomplish revisions at these final stages can compromise the effectiveness of the training system and the operational community's support for the system.

Because the traditional government procurement system is based on minimizing the competitive bid, one of the areas most likely to suffer is the TEAR process at the end of the system development. Separating the final TEAR stages from the primary system development is recommended. This procedure would assure the availability of sufficient time and resources to make the revisions before the system is submitted to an operational test and evaluation.

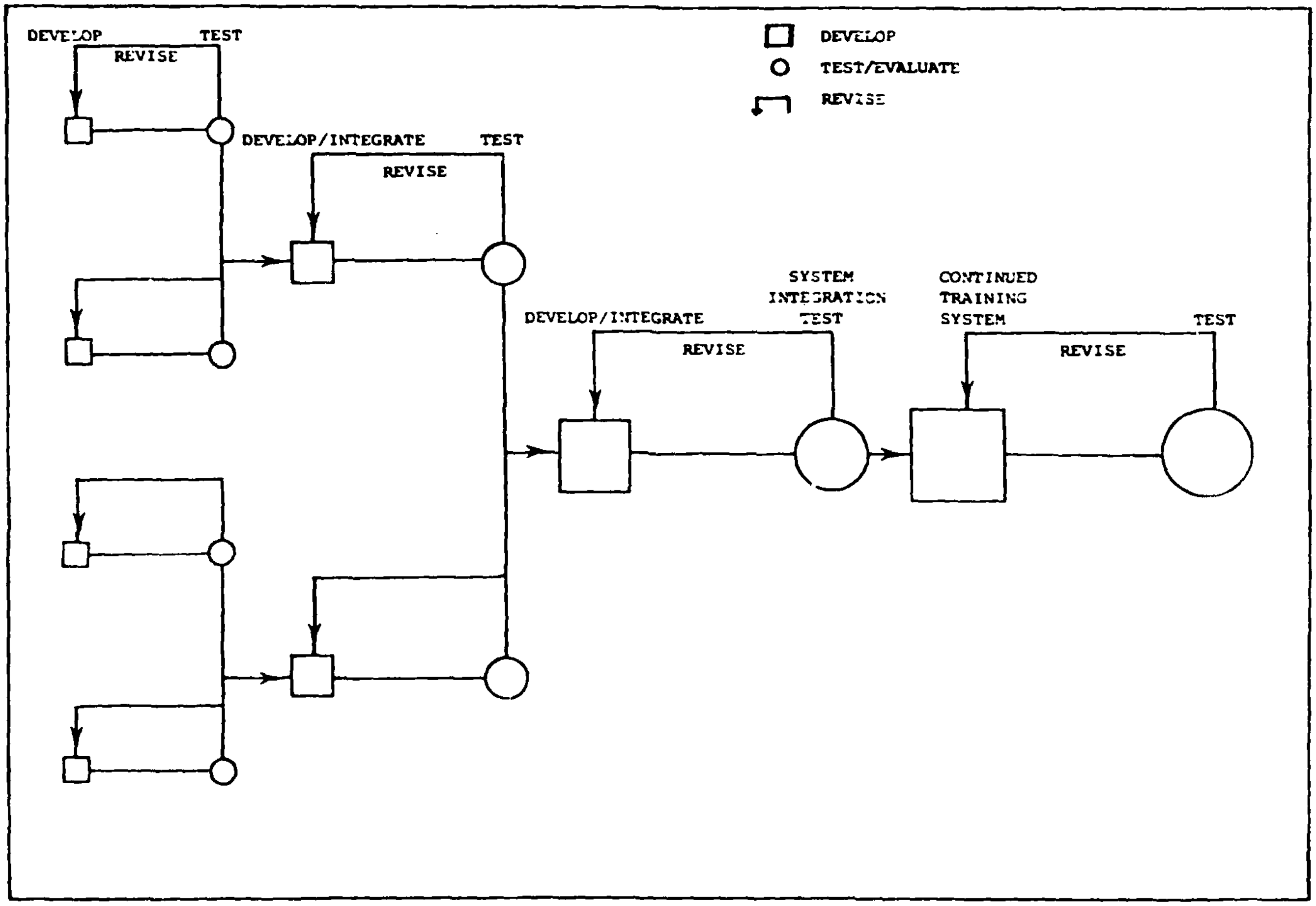

Figure 3. The Training System Development Process Includes a Continuous Cycle of Develop/Test/Evaluate and Revise (TEAR)

The end of the development cycle is arbitrary. Delivery of an operational training system may be followed by a final operational test and evaluation. But the process must be continued. Fleet equipments, procedures and personnel change overtime. Automated training systems must reflect these changes. Scheduled periodic review of the match between fleet training requirements and training system capabilities is necessary. Test and revision should continue throughout the life cycle of the training system to ensure that it meets the changing needs of the fleet.

DEGREE OF INSTRUCTIONAL AUTOMATION

In the past, instructors were essential in the training of tasks with speech output. Even though some instructional materials could be presented without an instructor (i.e., textbook or CAI), the trainee's performance (speech) had to be evaluated by the instructor listening to it.

Similarly, pseudo-pilots were essential for interactive simulations of tasks wherein the controller of some system or vehicle is given verbal instructions by the trainee. In many Navy training settings, both an instructor and a support person (e.g., pseudo pilot) are dedicated to the training of a single trainee (see Figure 4).

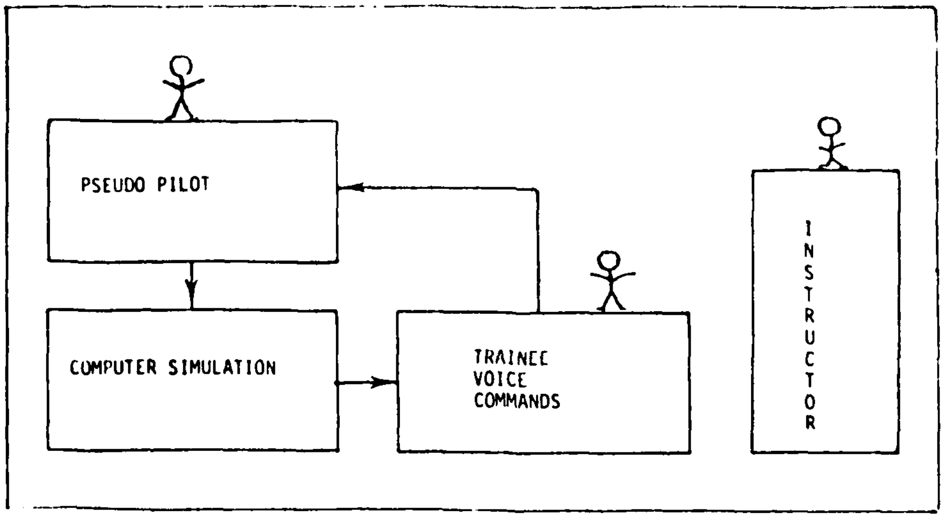

Figure 4. Typical Training Situation With Two People Supporting The Instruction Of One Trainee

Automated speech recognition has provided new opportunities to reduce the level of instructional personnel manloading by the partial (or total) automation of the pseudo pilot, the instructor, or both. Partial automation can mean a reduction of the number of students per instructor.

One of the challenges facing the training system design team is to determine the optimum degree of automation for a particular training system. Instructor models are becoming increasingly capable of adequately performing instructor functions such as:

- o Instruction (teaching)
- o Instructional Sequence Control
- o Scenario Generation
- o Performance Measurement and Evaluation
- o Performance Feedback
- o Record Keeping

Several NATRAEQUIPCEN reports have contributed to the conceptual development of automated instructor models (Chatfield and Gidcumb, 1977; Chatfield, Marshall, and Gidcumb, 1979; Chatfield, Klein, and Coons, in press; McCauley and Cotton, in press). Advancements in the field of artificial intelligence (AI) are beginning to contribute to the "intelligence" of instructor models. The authors project that by the mid-to-late 1980s the application of intelligent instructor models will be well within the technology. The level of "intelligence" in automated systems will evolve during the next decade. This evolution should result in the capability to apply very effective automated instructor models.

The development of instructor models, however, is expensive because of the software required. The challenge to the training systems development team is to weigh the software development costs against the reduction in instructor manpower costs over the projected life cycle of the system. This process assumes that equivalent training effectiveness will be achieved with human instructors and instructor models. However, an exception to this line of reasoning must be noted. In times of absolute manpower shortages, instructor models can reduce instructor manning levels, freeing instructors for fleet duty. In such cases, the cost of software model development may be secondary to meeting personnel manning requirements.

The strengths and weaknesses of instructor models relative to human instructors should be considered when making decisions about the degree of automation desired in a training system. Automated performance measurement and evaluation provide the potential benefit of complete objectivity. Trainees need not be concerned about possible bias of an individual instructor. Similarly, variance between instructors is eliminated with an instructor model. Performance criteria are standardized and do not fluctuate due to time and environmental influences.

Automated performance monitoring provides increased capability for record keeping. A large number of trainee performance measures can be recorded and tracked automatically during the training course. The extent of this performance data monitoring task would be beyond the scope of the human instructor.

On the other hand, experienced human instructors are capable of integrating subtle cues to a trainee's state of learning. Human instructors provide a source of personal communication that seems to be important for some students in a learning situation. While a natural language interface may be possible in future training systems, it will not approach the richness and flexibility of human dialog. Joplin (1980) has discussed the need for supplementing automated instruction with personal interaction among students and instructors. Finding the optimum level of automation for a particular training application is an important step in the ISD process.

The technological limitations of AST instructor models can be identified in three areas - speech recognition, trainee models, and performance measurement/evaluation/diagnosis.

Current limitations in automated speech recognition include constraints on vocabulary size and diminished recognition accuracy under "field" conditions. These constraints represent a limitation of the effective interchange between a trainee and an instructor model.

Every experienced human instructor uses his backlog of experience to form an internal model (or "schema") about how trainees should progress during a training course. The instructor can identify a "fast" or "slow" trainee by comparison to this schema. Instructor models can simulate a consensus schema of normal (or abnormal) progress, called a trainee model (or student model), but the training efficiency of the model will not necessarily exceed that of a good instructor. Wooldridge, Vreuls, and Norman (1977) tested two instructors and several automated adaptive logics and found that, while they varied in efficiency, the best logics were approximately equivalent to the better instructor.

Instructor models can provide automated performance measurement of many variables on each behavior of the trainee (speech or other). However, the development of valid performance measures in a difficult task is fraught with pitfalls such as what variables to measure, when to measure them, how to score them relative to some constant or varying criteria, and how to combine the scores into a meaningful set of performance indices (Vreuls and Wooldridge, 1977). The difficulties with a prototype performance measurement system in PARTS have been documented (McCauley, Helms and Semple, 1980). Ineffective automated performance measurement places constraints on the overall effectiveness of an automated training system. Although it may not be, strictly speaking, a technological limitation, the development of good automated performance measures is a difficult, time-consuming process. It requires continual interchange with the operational training community and a series of TEAR cycles.

ANALYSIS OF SPEECH TASKS FOR TRAINING

The three AST training systems sponsored by NAVTRAEQUIPCEN have been developed for tasks which share common speech functions. This category of tasks may be the primary candidate for AST applications; but any task

involving speech communications could be appropriate. The three tasks, GCA, AIC, and LSO, essentially involve air traffic control. The trainee must learn to extract visual information and provide speech output to a pilot. The speech output represents the primary action to be learned, although both the AIC and LSO task involve manual actions too. For all three tasks, simulation in support of training normally requires both an instructor and a person to simulate the actions of the pilot/aircraft. These kinds of tasks are prime candidates for an AST training system because of their emphasis on speech as the behavior to be learned, and their requirement for two people to support the training of each trainee.

Navy training tasks vary in the degree of speech behavior to be learned i.e., what proportion of the response repertoire is verbal? The decision about when to use AST in a training system may be based partly on this factor. An anlysis of the verbal communication requirements of a task is essential before deciding whether AST should be a candidate technology for a training system. The analysis should include definition of the vocabulary characteristics. Standardized phases of brief duration are more amenable to present AST than are unstructured and lengthy verbiage (Doddington and Schalk, 1980; Lea, 1980).

Team communication is another candidate for AST training systems. Members of the team with whom the trainee must communicate can be simulated by speech recognition, modeling, and speech generation. This application would be helpful when actual team members were not readily available to support the training scenario, or when training effectiveness could be enhanced by greater control over the actions of the team members.

The techniques involved in the AST training systems described above are complex, but simpler training applications of AST are possible. A vocabulary of four or five words/phrases could be used to replace most keyboard functions in a CAI system. A trainee getting "hands on" experience with equipment could be given instruction by speech generation. The trainee could be given voice control over the instructional selections using a few words, such as "Next" and "Review." These types of AST applications to training would be relatively simple and inexpensive.

AST has the potential to contribute to a variety of Navy training situations, including air, surface and subsurface. The following examples are based on the premise that any training where verbal communication is involved represents a candidate application of AST:

SONAR team training

CIC training

Docking training

LAMPS back-up training

AST also is applicable to non speech (or low speech) tasks for providing interactive audio instruction. Maintenance tasks would be candidates for providing "hands-on" training with interactive speech systems.

COMMON PITFALLS

Inadequate Trainee-Oriented Design

The functional characteristics of the interaction between the trainee and the system must be expressed thoroughly before software development begins. Human factors issues should be emphasized in the functional description. For example, the temporal characteristics of the interactive simulation must be stated, i.e., after the trainee terminates an utterance, the system will respond within one second.

In the ACE system, for example, three to five seconds may elapse before the simulated pilot responds to the trainee's verbal transmission. This has been cited by ACE trainees and instructors as an unacceptable response time, (McCauley, Root and Muckler, in press). For example, the trainee's task may require him to give a series of transmissions within a limited time. A delayed pilot response increases time pressure on the trainee. A specific example from the ACE system is given in Table 1 to illustrate the cumulative effects of inadequate system response time. As shown in the table, slow response becomes an even greater problem when it is coupled with a speech recognition error. The trainee attempts to transmit a series of advisories, some of which require a verbal response from the pilot. System delays in providing the pilot response make the task more difficult. The delays are doubled when a recognition error forces the trainee to repeat the transmission. A rare misrecognition requiring a repeat would be acceptable because pilots also may misrecognize transmissions occasionally. But a high frequency of misrecognized digit strings compounds the problem of a delayed verbal response from the pilot.

Initial system design goals should include optimized temporal interaction. Some delays will be unavoidable because of system constraints, but high priority should be given to the timing characteristics of trainee/system interaction.

Inadequate SME Input

Many Navy jobs are becoming increasingly complex as technology evolves. Specialization is becoming the norm. The vocabulary (or jargon) associated with specialized tasks is important and often reflects subtle aspects of the expert's task performance. Training experts, system analysts, and software programmers cannot be expected to master the subtleties of a task for which they are developing a training system. This is a case where a little knowledge can be dangerous. Superficial understanding of the task will be obtained by those working on the project. A SME with recent operational and training experience should be closely involved with the development of all aspects of the instructional material,

TABLE 1. INADEQUATE TEMPORAL RELATIONSHIP OF TRAINEE/SYSTEM VOICE INTERACTION

TIME (SEC.)	CORRECT TIMING	PROTOTYPE SYSTEM TIMING
00	TRAINEE: "Silverhawk, Port 130 for station"	TRAINEE: "Silverhawk, Port 130 for station"
01		
02	SYSTEM: "Roger 130"	
03		
04	TRAINEE: "Silverhawk, What State?"	
05		SYSTEM: "Roger 180"
06		TRAINEE: "Silverhawk, Port 130 for station"
07		
08		
09		
10		SYSTEM: "Roger 130"
11		TRAINEE: "Silverhawk, What State?"

course content, training objectives, practice exercises, and performance measurement. Periodic cross checks with a larger sample of operational SMEs is recommended.

Even subtle connotations of words used in instruction can contribute to the "not invented here" syndrome. For example, the term "advisory" was used incorrectly in the ground-controlled-approach instruction presented in PARTS (McCauley and Semple, 1980). Close-scrutiny by a dedicated SME can minimize errors in terminology and concept. Instructor models must be "intelligent" about all aspects of the job.

Inadequate Developmental Testing

The complexity of a training system with real-time speech interaction and automated instructor models should not be underestimated. Periodic stages of test, evaluation and revision (TEAR) should be scheduled during system development. The later stages of the development are particularly important for developmental testing because of the critical integration of all the models and subsystems. It is highly recommended that the TEAR process include observation of a small set of people progressing through the entire curriculum. In-plant personnel and SMEs are candidates for these initial observations. After appropriate revisions have been made, an actual trainee should be observed interacting with the training system.

The critical final stages of the TEAR process often are perfunctory because of the desire to deliver the product within a time schedule. Adequate time and resources should be allocated for these important stages of system development including the necessary revisions. Complex training systems must undergo this painful test and revision stage to achieve the desired training effectivenesss and user acceptance.

SECTION VI

HOW TO USE THE DESIGN GUIDES

INTENDED AUDIENCE

As stated in the Introduction, these design guides are directed toward training analysts, subject-matter-experts, and systems analysts to channel and facilitate their joint efforts in developing detailed functional specifications for their particular training system application. The design guides are expected to be used by both government and contractor personnel involved in the procurement and development of AST training systems.

MAJOR DIVISIONS

The design guides are divided into four categories: Automated Speech Systems (Appendix A), Instructor Model (Appendix B), Simulation and Event Control (Appendix C), and System Integration (Appendix D). The first category is the most extensive, since AST is the focus of this project. The remaining categories were developed under the assumption that they are part of an AST training system. Much of the information in them, however, is appropriate for non-speech systems as well. The recommended design procedure is given in Figure 5.

FORMAT

The four design guides are presented in the same format. Narrative, comments and supporting information are presented first. Then the specific information, data, and recommendations which make up each design guide follow.

In developing the design guidelines the authors had hoped to present more specific information than was ultimately possible. This difficulty occurred for two reasons: 1) a scarcity of design data on speech systems in field applications, and 2) the orientation toward generic design, applicable to a broad range of training applications. The authors believe, however, that when the guidelines are followed carefully, an effective AST training system will result.

PREREQUISITES

These design guides are intended to be used when AST is being considered for inclusion in an automated training system. A full ISD process should be followed during the system development, and the early task analysis stages should be completed before using these design guides. The design guides should be helpful from that stage through the development of the functional specifications of the system.

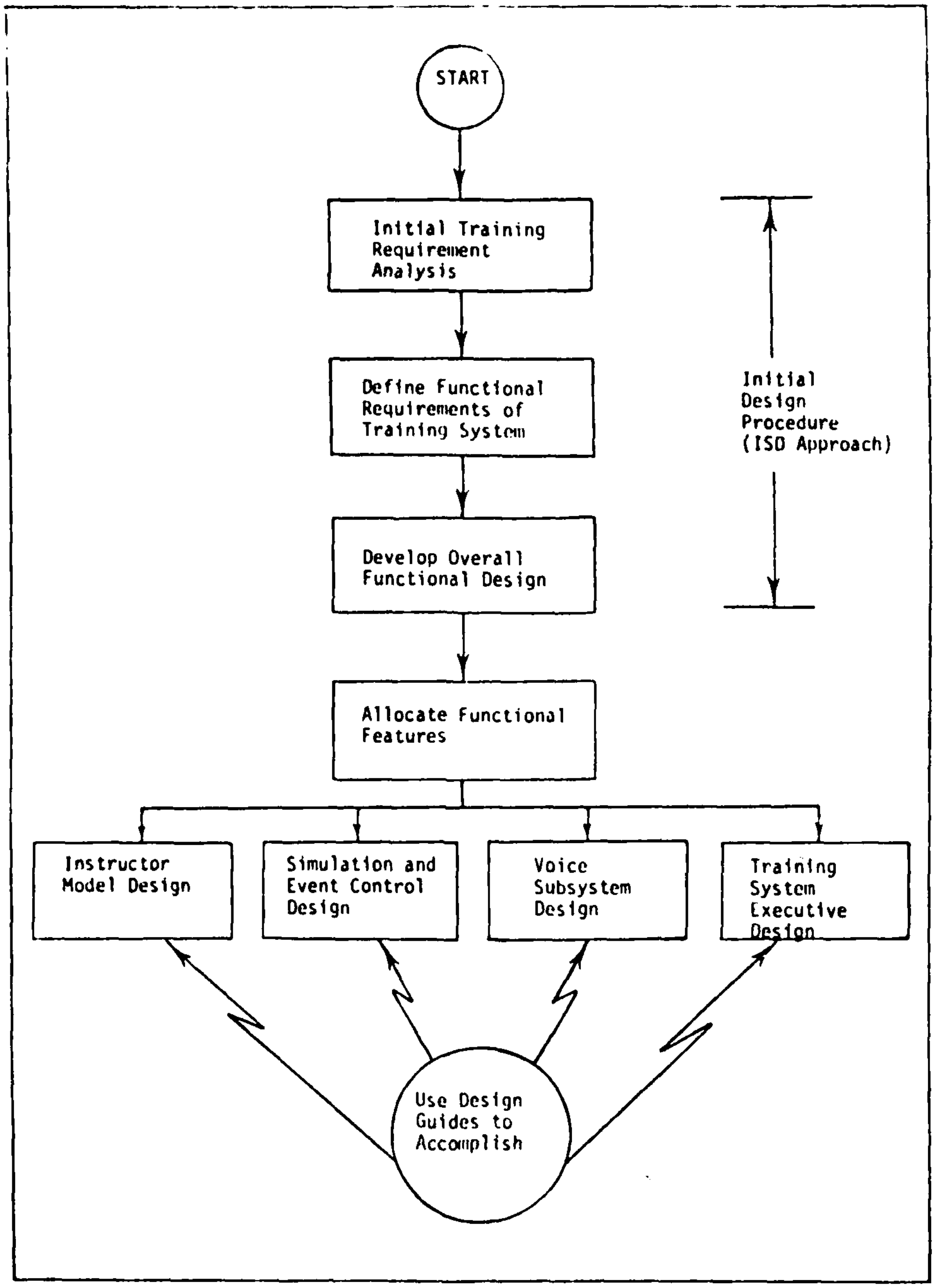

Figure 5. The Role of Design Guides in the Design Process

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APPENDIX A

AUTOMATED SPEECH SYSTEM DESIGN GUIDE

APPENDIX A

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PART 1

SPEECH RECOGNITION SYSTEMS

INTRODUCTION

The speech system design guide is divided into two parts. The first covers the design of speech recognition systems and the second speech generation (synthesis) systems. The reader is reminded that this design guide only applies to the design of those training systems involving verbal interaction between the trainee and the training device. The design guide assumes that the user has a working knowledge of automated speech technology (AST) and detailed knowledge of the training task to which it will be applied.

The design guidelines for each section are preceded by related discussion and amplifying comments.

This design guide is intended to encompass the following design procedure for speech recognition systems, as depicted in Figure A-1:

1. Extend the ISD process to include speech task analysis for a planned training system development endeavor.

2. Identify the speech recognition system functional design requirements from the task analysis.

3. Update knowledge about the automated speech technology state-of-the-art.

4. Make a technical projection of whether the design requirements for the speech recognition system can be satisfied by the technology within the time frame in which the training system will begin to operate.

5. Decide whether to continue.

6. Develop the speech system operating and human factors design so that the operation of the system can be thoroughly described for all personnel involved with the design and development process.

7. Develop the speech system specification so that it becomes an effective document for the designers, developers, and users of the training system.

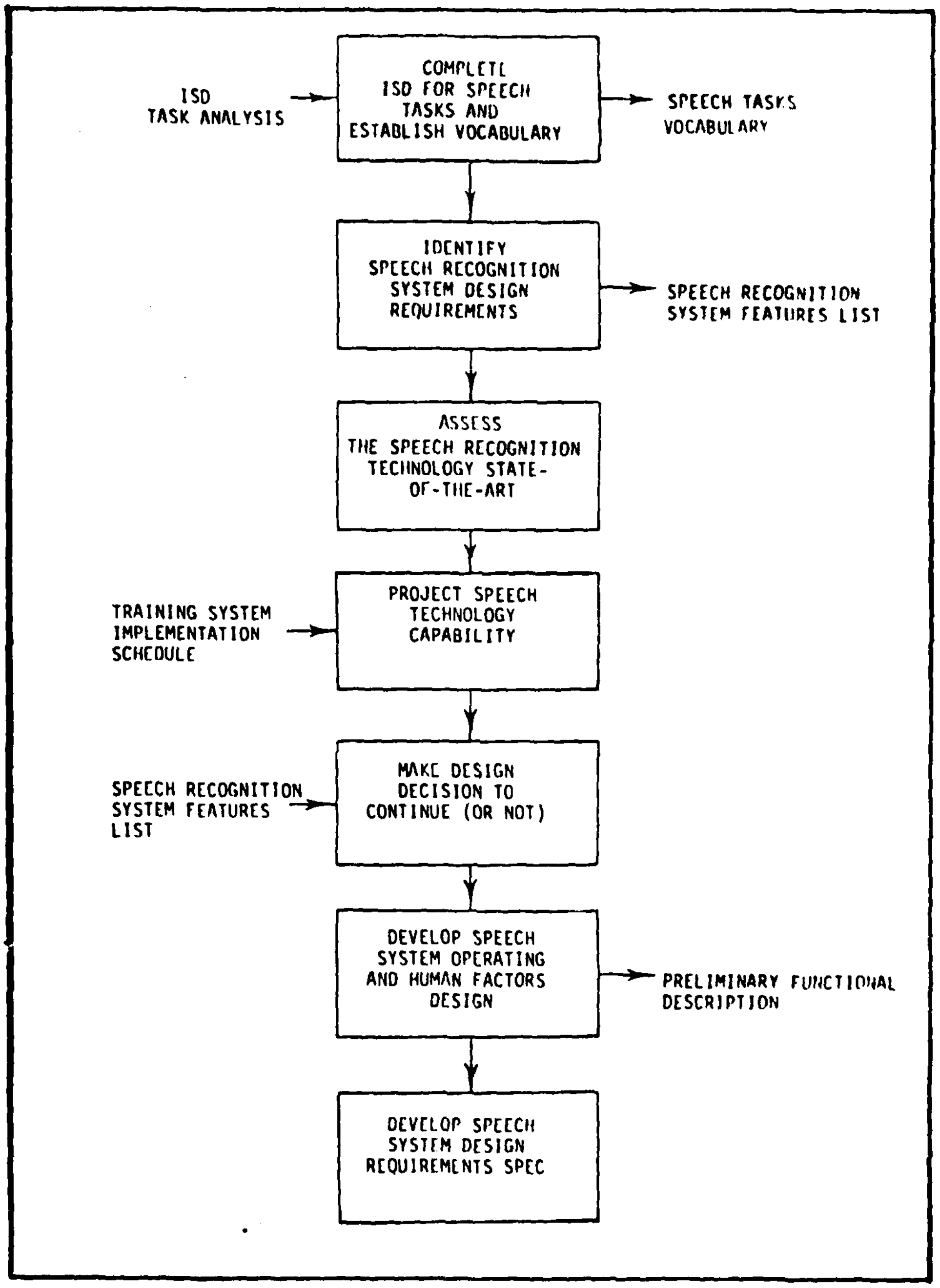

Figure A-1. Work Flow for Speech Recognition System Design

At the time of writing the ISD formal process, as depicted in Figure A-2, does not include speech task analysis. However, suggestions have been made with the military community that the ISD formal process be expanded to include speech analysis. For the purpose of this design guide, Speech Task Analysis is intended to include both speech recognition and speech generation.

It is likely that speech recognition technology will move rapidly in the next five years (through 1986). System designers will need to continually stay abreast of developments which will assist them in making prudent design decisions. However, if a prototype system is envisaged, the speech recognition technology may be adequate for the performance of limited training, but more advanced technology may be required for the production training system. Thus, production timing and technical projection are critical system design factors to be considered early in the design process.

In regard to operating and human factors design, failure to thoroughly describe the operation of the training system early in the design process has a very detrimental effect on system effectiveness and on the successful acceptance of the product by the user community.

TASK AND VOCABULARY ANALYSIS

Speech tasks are a subset of training tasks subject to the formal ISD process. They can be reduced to a basic unit of verbal communication called an utterance, which may consist of a word, digit, or phrase. There are two basic categories of utterances: 1) utterances to be said <u>by</u> the trainee in the conduct of training; and 2) utterances to be said <u>to</u> the trainee by the instructor (or others) during training.

Utterance Types

The utterances may differ in specific segments of training and should be identified accordingly. The utterance can be a single word, a single digit, multiple words (phrases), and multiple digits in combinations. Current speech recognition technology is capable of recognizing utterances consisting of single words or groups of words organized into short phrases.

Commonly used phrases may be similarly constructed using different words and digits. Consider:

"turn left 180^{o}"

"turn left 277^{o}"

the phrase structure remains the same only the digits change. Now consider:

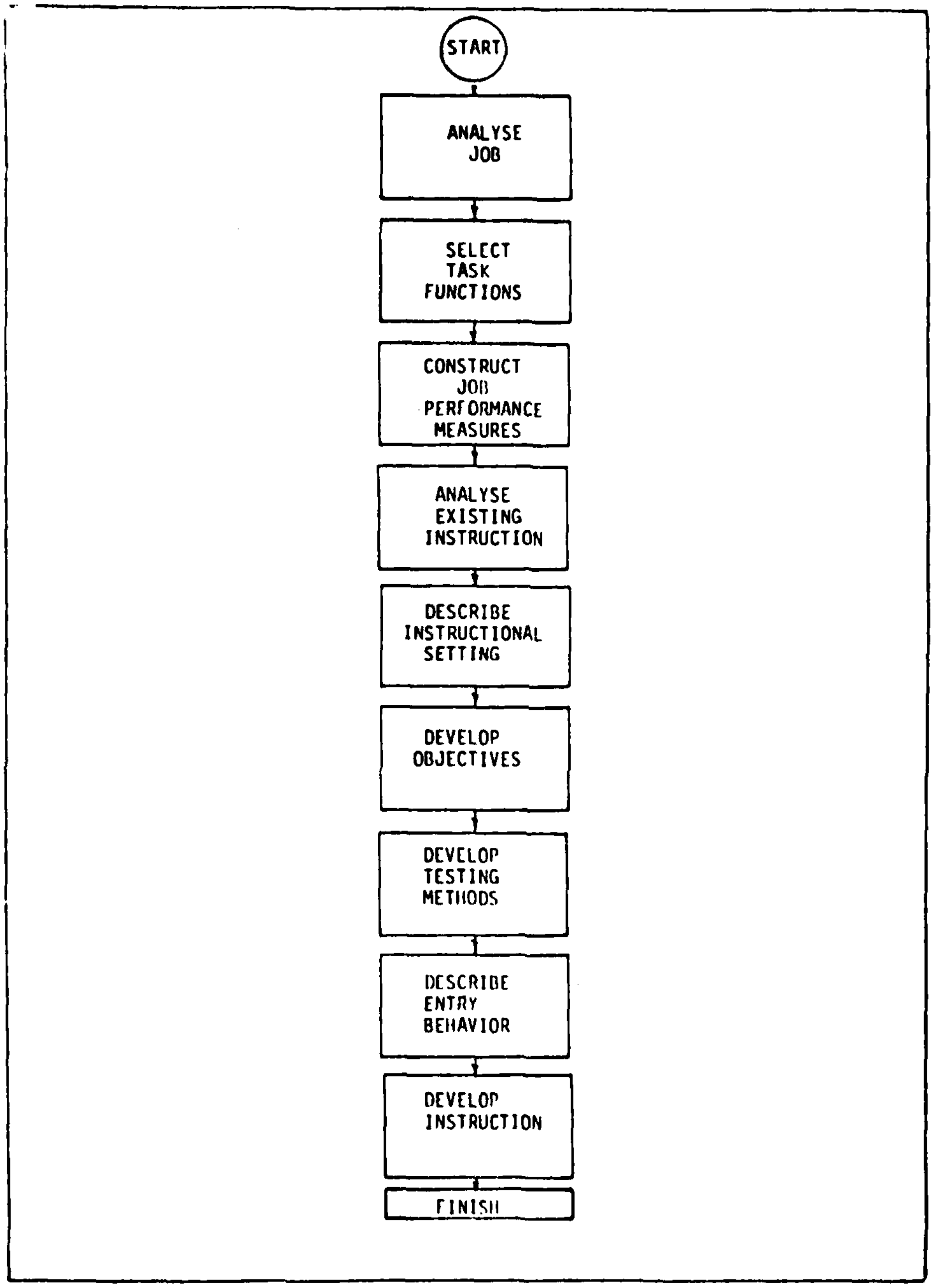

Figure A-2. Abridged Instructional System Development Flow for Initial Training Analysis

"turn left 277^{o}"

"turn right 277^{o}"

the phrase structure remains the same, only one word changes. Commercial speech recognizers capable of handling from 12 to 1000 utterances are available to training system designers at the time of writing. The capacity for the larger vocabularies (over 100 utterances) often is obtained using subsetting procedures, wherein only some portion of the entire vocabulary is active at any one time.

Develop a Speech Training Task Vocabulary

Table A-1 shows a task vocabulary which was developed for the Air Controller Exerciser (see the earlier discussion in Section IV). It contains utterances with embedded digits and embedded words and was developed from a series of speech communications tasks used in the well-structured Air Intercept Control Environment. Table A-2 shows a task vocabulary applicable to the Landing Signal Officer Training System (LSOTS) (LSO NATOPS Manual, 1975). In the carrier landing environment LSOs often use alternative phrasings that have different word structure but the same meaning. The LSO operating environment also allows emphasis to be imposed on words to indicate to the approaching pilot the degree of reaction indicated, such as "Power" or "Power!!!" (the latter said with much emphasis). These kinds of vocabulary idiosyncracies present the training system analyst with a multi-faceted problem. The successful operation of the training system will depend very heavily on satisfactory solutions. Pointers for the vocabulary development are:

o Categorize the speech tasks into operational segments (subsetting). Identify singularities and commonalities.

o Where a phrase differs only by the use of one word, create two separate phrases.

o Seek alternative means for using the same utterance with differing degrees of emphasis.

o Seek alternative words to those which have acoustically similar structure (like "niner" and "fiver" or "port" and "fort").

o Use the services of a linguist who is familar with the speech recognition technology to review the proposed vocabulary for acoustical confusibility. If conflicts occur, find alternative utterances.

o Finalize the vocabulary with the user community. This step also may aid in standardizing the vocabulary for both the training and operational environments.

TABLE A-1. SPEECH TASK VOCABULARY FOR AIR CONTROLLER EXERCISER

The following notations are used:

xxx - is the heading or bearing spoken as single digits
yy - is the range spoken as a whole number
fff - is the fuel spoken as a single digit
zz - is the altitude spoken as a whole number
m - is the speed (mach) as a single digit
n - is a single digit number
c/s - Aircraft call sign

** - Phrase may be eliminated to improve speech recognition

1 = AIC1
2 = ROGER
3 = RUTH
4 = SAY AGAIN
5 = CORRECTION **
6 = DISREGARD THIS TRANSMISSION**

PHRASE NO.	PHRASE
7	= BOGEY (pause) xxx (pause) YY
8	= STATION (pause) xx (pause) YY
9	= BOGEY TRACKING (pause) xxx
10	= BOGEY TRACKING (pause) xxx (pause) SPEED (pause) POINT
11	= c/s PORT (pause) xxx
12	= c/s STARBOARD (pause) xxx
13	= c/s VECTOR (pause) xxx
14	= c/s PORT HARD (pause) xxx **
15	= c/s STARBOARD HARD (pause) xxx **
16	= c/s VECTOR HARD (pause) xxx **
17	= c/s PORT (pause) xxx (pause) FOR BOGEY **
18	= c/s STARBOARD (pause) xxx (pause) FOR BOGEY **
19	= c/s VECTOR (pause) xxx (pause) FOR BOGEY **
20	= c/s MARK YOUR TACAN
21	= c/s WHAT STATE
22	= ROGER STATE (pause) fff (to CAP) (fff is fuel in hundreds of pounds)
23	= I HAVE CONTROL OF c/s (to SWC)
24	= c/s STATE (pause) xxx (to SWC)

(continued)

TABLE A-1. (Continued)

25	= c/s ON STATION (to CAP)
26	= BOGEY SINGLE (pause) ALTITUDE (pause) zz THOUSAND
27	= c/s BREAKING AWAY
28	= SPLASH (pause) n BOGEYS
29	= HEADS UP (pause) n BOGEYS
30	= BOGEY JINKING LEFT
31	= BOGEY JINKING RIGHT
32	= BOGEY SPLITTING
33	= ROGER YOUR BOGEY TRACKING (pause) xxx
34	= NEGATIVE BOGEY (pause) xxx (pause) YY
35	= BOGEYS MULTIPLE (pause) ALTITUDE (pause) zz THOUSAND
36	= STRANGER (pause) xxx (pause) YY
37	= STRANGER TRACKING (pause) xxx
38	= STRANGER TRACKING (pause) xxx (pause) ANGELS (pause) zz
39	= STRANGER OPENING
40	= c/s EASE TURN
41	= c/s TIGHTEN TURN
42	= c/s (pause) xxx (pause) YY
43	= c/s ANGELS (pause) zz
44	= c/s PORT (pause) xxx (pause) FOR RENDEZVOUS **
45	= c/s STARBOARD (pause) xxx (pause) FOR RENDEZVOUS **
46	= c/s VECTOR (pause) xxx (pause) FOR RENDEZVOUS **
47	= c/s RADIO CHECK
48	= BOGEY IN THE DARK
49	= CAP IN THE DARK
50	= c/s MY OCTOPUS IS BENT
51	= c/s EMERGENCY
52	= c/s DETACH PORT (pause) xxx (pause) FOR SEPARATION **
53	= c/s DETACH STARBOARD (pause) xxx (pause) FOR SEPARATION
54	= c/s CONTINUED (pause) xxx
55	= c/s BREAKAWAY (pause) xxx
56	= c/s ANCHOR PORT
57	= c/s ANCHOR STARBOARD
58	= c/s STEADY
59	= c/s LOST COMMUNICATIONS INTENTIONS
60	= ROGER LOST COMMUNICATIONS INTENTIONS
61	= c/s PORT (pause) xxx (pause) AS BOGEY **
62	= c/s STARBOARD (pause) xxx (pause) AS BOGEY **
63	= c/s VECTOR (pause) xxx (pause) AS BOGEY **

TABLE A-2. SPEECH TASK VOCABULARY FOR
LANDING SIGNAL OFFICER

INFORMATIVE CALLS

Used to inform pilots of existing situations.

TRANSMISSION	MEANING	RESPONSE (Aircraft in Manual Mode)	RESPONSE (Aircraft in APC Mode)
"You're (a little) high."	Aircraft is (slightly) above optimum glide-slope.	Adjust sink rate with power/nose attitude to establish center ball.	Adjust sink rate with nose attitude to establish center ball. (Avoid using in close.)
"You're (a little) low."	Aircraft is (slightly) below optimum glide-slope.	Adjust altitude immediately.	Adjust altitude immediately.
"You're going high (low)."	Unless corrected, aircraft will go above (below) optimum glide-slope.	Adjust sink rate with power/nose attitude to maintain center ball.	Adjust sink rate with nose attitude to maintain center ball.
"You're lined up left/right."	Aircraft has undershot/overshot centerline.	Reestablish centered lineup.	Reestablish centered lineup.
"You're drifting left/right."	Aircraft is drifting left/right of center-line.	Correct lineup to centerline.	Correct lineup to centerline.
"You're fast/slow."	Self explanatory.	Adjust nose attitude/power to establish optimum AOA.	Not used.
"Roger Ball" (AUTO/MANUAL/Coupled as appropriate)	LSO acknowledges pilot meatball acquisition.		
"Paddles Contact"	LSO assuming control from CCA.		

(continued)

TABLE A-2. (Continued)

IMPERATIVE CALLS

Used to direct pilot to execute a specific control action. MANDATORY IMMEDIATE RESPONSE.

TRANSMISSION	MEANING	RESPONSE (Aircraft in Manual Mode)	RESPONSE (Aircraft in APC Mode)
"A little power."	Aircraft is decelerating; unless corrected aircraft will become slow/low.	Correct with power.	Call not used.
"Power."	Aircraft is low/slow.	Add power.	Add power and disengage APC. Refer to Note.
"Go Manual."	Disengage APC.	Not Used.	Add power and disengage APC. Refer to Note.
"Attitude"–("A little attitude.")	Aircraft nose is low/flat attitude.	Increase nose attitude (slightly).	Increase nose attitude (slightly) to reduce sink rate.
"Right/Left for lineup" (Use in close or at the ramp.)	Aircraft will land left/right if not corrected.	Correct lineup to centerline, then level wings.	Correct lineup to center line, then level wings.
"Bolter."	Self explanatory.	Add 100 percent power and execute bolter in accordance with model NATOPS manual.	Add 100 percent power and execute bolter in accordance with model NATOPS manual.
"Waveoff" or "Waveoff, Foul deck" (Whenever waveoff lights are keyed.)	Self explanatory.	Execute waveoff in accordance with model NATOPS manual.	Execute waveoff in accordance with model NATOPS manual.
"Cut."	Release signal, as necessary to landing.	Response mandatory for all prop landings and jet barricade engagements.	Response mandatory for barricade engagements.
"Speedbrakes."	Speedbrakes are extended.	Retract speedbrakes.	Retract speedbrakes.
"Extend Speedbrakes."	Self explanatory.	Comply.	Comply.
"Drop your hook."	"	"	"
"Drop your gear."	"	"	"
"Drop your flaps."	"	"	"
Uncouple.	Disengage ACLS.	Disengage ACLS	Disengage ACLS.

TABLE A-2. (Continued)

PRECAUTIONARY CALLS

Used to direct pilot's attention to potential difficulties and prevent possible control errors.

TRANSMISSION	MEANING	RESPONSE (Aircraft in Manual Mode)	RESPONSE (Aircraft in APC Mode)
"Check your lineup."	Aircraft lineup is not optimum.	Correct lineup drift or position.	Correct lineup drift or position.
"Don't settle"- "Don't go low."	Aircraft will settle below optimum glide-slope if not corrected.	Check sink rate and meatball to avoid settling below glide-slope.	Check sink rate and meat-ball to avoid settling below glideslope.
"Don't climb"- "Don't go high."	If not corrected air-craft will climb above optimum glideslope.	Check sink rate and meatball to avoid climbing above glide-slope.	Check sink rate and meat-ball to avoid climbing above glideslope.
"Keep your nose up"- "Hold your attitude."	Pilot tends to drop nose.	Don't drop nose.	Don't drop nose.
"Hold what you've got."	Self explanatory.	Hold present (optimum) stick and throttle positions.	Hold present (optimum) stick position.

(continued)

There may be no simple solution to the problem of emphatic words and phrases. However, recognizing that the majority of Isolated Word/Phrase speech recognizers are speaker dependent, one solution may be to "sample " the utterance at different degrees of emphasis, i.e. to treat them as different utterances. Another solution is to provide heavy support to the speech recognizer in the form of "understanding" software that makes use of all available task and context cues.

TIME CONSTRAINTS

Recognition Response Time

The initial analysis of the speech recognition system must include identification of the time constraints in which speech recognition must occur to maintain realistic pacing of the task. Approximately one second is the maximum time that should be allowed for recognition to take place in an interactive system. After one second, the training system should begin to provide some form of visual or aural response indicating that recognition has taken place. Without adequate response time, the user may engage in repeated efforts to get the training system to respond. This interferes with the training scenario and detracts from user acceptance.

Pausing Between Utterances

Most current recognition systems require the user to pause between each utterance for approximately 100 to 200 milliseconds. This pause length is natural for a human speaking in non-stressful circumstances. However, if the training circumstance becomes stressful (and most will do so at some point), the trainee will tend to omit pauses, severely degrading recognition accuracy. Recent progress in ASR technology promises to reduce the minimum pause to 50 milliseconds or less.

Phrase Length

Current recognizers require a vocabulary item to be input within some maximum time limit. This limit varies with the manufacturer, but most are 1 1/2 to 5 seconds. No pause can occur between the words of a phrase defined as a vocabulary item.

DEFINING THE SPEECH RECOGNITION SYSTEM REQUIREMENTS

The requirements of the speech recognition system must be specified for each training system application. Table A-3 lists the potential requirements which should be considered. For ease of use the table has been subdivided as follows:

<u>Speech Characteristics</u> - the task-oriented vocabulary.

<u>Functional Design Features</u> - how the system accomplishes the job of recognition.

Table A-3. SPEECH RECOGNITION SYSTEM POTENTIAL REQUIREMENTS

A <u>SPEECH CHARACTERISTICS</u>

- Continuous Speech Recognition
- Connected or Limited Continuous Speech Recognition
- Isolated Word (Phrase) Recognition
- Vocabulary Size
- Subsetted Vocabulary Size
- Stylization Requirements

B <u>FUNCTIONAL DESIGN FEATURES</u>

- Speech Data Collection
- Speech Recognition Practice
- Recognition Test
- Confusibility Index
- Repeated Speech Data Collection
- Speech Recognition Feedback
- Syntax Control
- Understanding
- Multiple Concurrent Users
- Methods for Signing On
- Speech On/Off Control

(continued)

Table A-3. (Continued)

C RECOGNITION PERFORMANCE CHARACTERISTICS

- Speaker Independent/Dependent
- Transmission Accuracy
- Rejection Error
- Speaking Rates
- Pause Duration
- Reaction Time (after completion of transmission)
- Rejection Thresholds
- User Variabilites
- Environmental Perturbations

D MISCELLANEOUS FEATURES

- Projected Cost
- Speech Input Device
  type of microphone
- Speech Input Level Control
  automatic gain control, manual gain control with Vu meter

Recognition Performance Characteristics - how the speech recognition systems performs.

Miscellaneous Features - not covered within the foregoing categories.

Speech Characteristics

Continuous Speech Recognition - is characterized by a large vocabulary, long utterances and few pauses.

Connected (or Limited Continuous) Speech Recognition - allows a series of discrete words or phrases to be spoken without pausing in a maximum time span (normally 2 - 5 seconds). Similarly, digit strings can be recognized without pausing between the digits.

Isolated Word (Phrase) Recognition - requires pauses between discrete words and/or phrases which must be no longer than within a maximum time span (normally 1 1/2 - 5 seconds). A digit string which is used repeatedly, like "BRAVO 129", is considered to be a discrete word. Digit strings which vary will require pausing between the digits, like "TURN TO... 2...7...5... DEGREES."

Vocabulary Size - can be up to several hundred words and or phrases, or multiplied to larger vocabularies by subsetting.

Subsetted Vocabularies - vocabularies can be partitioned into subsets as a function of the operating environment (sometimes referred to as task syntax or task oriented grammar). This is usually done as a means of limiting the vocabulary size which must be actively processed. Subsetting can be used either to improve recognition accuracy through decreasing the active vocabulary or to increase the maximum vocabulary size.

Stylization - refers to the constraints imposed on the speaker by the recognition system in regard to pausing, volume, and pronunciation. Proper pausing is essential for isolated word recognition. The pause requirements imposed by the recognition process must be consistent with the operational language. Stylization constraints are a reflection of limitations in current recognition technology. As the technology advances, stylization constraints will be reduced.

Function Design Features

Speech Data Collection - takes a sample of the speech for the defined vocabulary spoken by each user of a speaker dependent system. These samples become the template or reference pattern for all subsequent recognition.

Speech data collection is conducted when a trainee first uses the system, when a new vocabulary word or phrase is added, and when speech recognition performance becomes degraded.

Speaker-dependent recognizers currently require 2 - 10 samples for each word/phrase. In some systems, part of the original sample set should be updated each time the trainee signs-on. On other systems, sample updating is rarely required. Future speech recognition systems are expected to optimize the vocabulary speech pattern information by periodically updating the sample with correctly recognized words/phrases uttered during the conduct of training.

Samples should be collected in the context of the task(s) to be learned. Visual prompts are preferable to audio prompts for speech data collection to preclude the trainee emulating the characteristics of the speech generation system.

Speech Recognition Practice - facilities should be provided for the trainee to practice speech recognition. This will lead to consistent speech and better recognition performance.

Recognition Test - is a means of evaluating speech recognition system accuracy indpendent of the training task. This can be done simply by providing visual or audio information of what has been recognized.

Confusibility Index - is a means of relating the probability of recognition of each word or phrase to other words and phrases in the vocabulary. This is a special measurement feature of recognition test. The total matrix may be displayed, or, alternatively, only those words and phrases with critical confusion. The confusion matrix also can be used to prompt the retraining of confused words and phrases.

Repeated Speech Data Collection - should be used to eliminate confused or rejected vocabulary words and phrases. These conditions tend to occur when there are changes in speech characteristics due to fatigue, stress, colds, flu, and changes in ambient noise.

Speech Recognition Feedback - is information provided to the trainee (and instructor) about the words and phrases which have been recognized. Feedback is essential but it must not interfere with the conduct of the training task. In some instances it may not be advisable to provide feedback until completion of the immediate task.

Syntax Controls - are rules which govern the use of the vocabulary in an operational context. In specific event sequences certain phrases have an extremely high probability of being correct. Software representation of this knowledge can improve recognition accuracy.

Understanding - is analogous to an artificial intelligence process and provides a higher order knowledge (above speech recognition which is based on acoustic pattern matching) to determine what has been said. Software representation of task and linguistic knowledge can improve recognition accuracy.

Multiple Concurrent Users - system designers may have to consider the use of multiple recognition systems working with one host computer to provide a multiple station training system. Recognition for each trainee must be independent of all other trainees. Speech recognition reaction time for an individual trainee's station should not exceed one second.

Methods of Signing On - for speaker dependent systems, the speech pattern data of a trainee must be bought into the foreground each time he signs on the system. In addition, the trainee's professional data, past history, and performance on the training system also have to be in the foreground. This information should be maintained on a diskette (or equivalent) which is inserted into the training system each time he uses it. This diskettte becomes the trainee's information file during training.

Speech On/Off Control - is recommended for task oriented vocabulary systems, as the discrete on/off action alerts the system that speech recognition is expected of it. Microphone keys or foot switches are recommended. Voice operated switches may be appropriate although caution is recommended because of the potential loss of valuable acoustical information at the onset of the word or phrase.

RECOGNITION PERFORMANCE CHARACTERISTICS

Speaker Independent/Dependent - the majority of current speech recognition systems are speaker dependent. Exceptions are those systems in which digits, words or simple phrases are said by any speaker, often in response to a series of audio prompted questions. Speaker dependency will continue to be the rule for training systems until future, non-task oriented, large vocabulary, speaker independent recognition systems become available.

Recognition Accuracy - measures must account for correct recognitions, the incorrect recognitions and non-recognitions (rejections) of valid vocabulary. Percent transmission accuracy (TA) is hereby defined as:

$$TA = \frac{\text{\# of valid transmission} - (\text{\# of incorrect recognitions} + \text{\# of non-recognitions})}{\text{\# of valid transmissions}} \times 100$$

A valid transmission refers to a programmed vocabulary item in the form of digits, words, phrases and combinations thereof.

Rejection Error - of a speech recognition system must account for the non-valid transmissions made by the user and the non-valid recognitions made by the system. Percent rejection error (RE) is hereby defined as:

$$RE = \frac{\text{\# of non-valid recognitions}}{\text{\# of non-valid transmissions}} \times 100$$

A non-valid transmission refers to a non-programmed vocabulary item in the form of digits, words, phrases, combinations thereof, and other utterances like "ah, umm."

Speaking Rates - most current recognizers will accept an utterance with a maximum duration (depending on the manufacturer) and will accept up to 50 utterances per minute. Current advances in the technology reportedly provide successful recognition of up to 180 words per minute.

Pause Duration - most current systems require pauses between utterances to be greater than 100 milliseconds. Again, current advances reportedly have reduced the pause duration to less than 50 milliseconds.

Reaction Time - An interactive system should respond within one second after completion of an utterance.

Rejection Thresholds - define the relationship between correct recognition, incorrect recognition/word substitution error, or rejection of a transmission. They are normally preset by the manufacturer. The unpublished industry's norm for recognition/rejection settings is considered to be 95% correct recognition rate, with 3% rejection rate and 2% word substitution. In some applications, like Command and Control, a word substitution rate of .005% is the minimum acceptance for initiating critical commands whereas a 10% rejection rate is operationally acceptable. Thus, user adjustment of rejection thresholds is desirable.

Speech Variability - within a speaker can arise from many sources including stress, fatigue, and health (cold, flu, etc.). Speech variabilities are associated with decreased recognition performance.

Environmental Perturbations - are defined as environmental factors that influence speech recognition such as ambient noise, vibration, high G, etc. These factors may be overcome to some extent by repeated voice data collection with the environmental disturbance present.

Miscellaneous Features

Projected Cost - Currently speech recognizers vary in cost from approximately $1,000 to $100,000 per unit, depending on capability. Cost comparison of systems is difficult because their features and capabilities vary greatly. Furthermore, standardized performance specifications do not exist at the present time. Cost estimates should be based primarily on

three factors: 1) will the recognizer stand alone or will there be software to give functional support to recognition; 2) what type of speech recognition is required - isolated word, connected word, or, (in the future) continuous speech; and 3) what is the size and structure of the vocabulary that must be handled.

Speech Input Device - the system designer may be confronted with a user requirement that the normal operational type of input device be used, for example, a telephone handset. Whenever possible, a noise-cancelling boom microphone should be selected for its consistency of input.

Speech Input Level Control - automatic gain control of the trainee speech audio input to the recognizer is preferable to manual control with a Vu meter because the former method provides consistency.

REASSESSING THE SPEECH TECHNOLOGY STATE-OF-THE-ART

Speech recognition systems are becoming more compact and more capable with the advent of medium to large scale integrated electronic component technology. While the breakthrough to unrestricted continuous speech still may be years away, ongoing improvements will continue in isolated phrase and limited continuous speech recognizers. These improvements will warrant reassessment of the technology each time a training system design or modification is considered. The objective here is to update a "current" technology baseline. The technology assessment should be carried out on a feature-by-feature basis using a similar listing to that shown in Table A-3.

Each feature should be related in a systematic manner to: 1) the most recent experience gained with specific speech recognition systems operating in the field, and 2) the latest claims made by manufacturers in regard to a specific recognition product capability.

"Hands-on" exposure is a necessity to evaluate recent system experience in the context of the requirements of the system under development.

In regard to manufacturers latest claims, one method for comparison which gives a view of advancing technology is to review the expanding capability of a line of recognizers produced by the same manufacturer over time.

MAKING A SPEECH RECOGNITION TECHNOLOGY PROJECTION

Having established the current state-of-technology, the training system design team is confronted with making a projection of where the technology is likely to be while the training system is being developed.

At the time of writing, this is a difficult task because of the following factors:

1. Basic research and development in the realm of unrestricted continuous speech is being conducted by large corporate entities like IBM, Bell Labs and Texas Instruments, who guard their knowledge until the product is publicly introduced.

2. In the immediate future, systems development firms have the potential to use imaginative computer programming to promote comprehensive task-oriented speech "understanding" systems while using 1979-80 generation recognizers.

3. The speed at which industry advances the technology is directly related to the number of speech recognition system applications being made or updated in the field.

However, in terms of voice interactive training system development, the technology projection must be completed before any attemps are made to determine whether a match between speech recognition requirements and the technology is feasible. There are six key points on which the projection should be made. These are:

1. What type of recognition mechanization will be available in the "system build" time frame? (isolated word, limited connected speech, or continuous speech).

2. What will be the degree of speaker independence? (total, initial speech data collection required, frequent update data collection required).

3. What is the expected recognition (transmission) accuracy in the operational environment?

4. Will there be any timing or processing constraints imposed on the training system by the available technology?

5. Will the available technology foster user acceptance of the speech interface?

6. Does the cost of the speech recognition system exceed the training system procurement budget?

Milestone projects from NAVTRAEQUIPCEN, like PARTS and ACE, have evolved through prototype system developments. Prudent training/systems analysts who begin with prototype system development, should attempt to project whether future technology will be commensurate with the greater demands of the production system.

MATCHING TECHNOLOGY TO SYSTEM REQUIREMENTS

Based on the definition of the speech recognition system requirements and the technology projection, it will be possible to determine whether there is a match. If there is not a complete match across the spectrum of requirements listed in Table A-3, then the training system requirements must be reduced and the matching process reiterated.

Practically speaking, reiteration could compromise the system requirements to such an extent that the training system would no longer satisfy the user requirements. Full communication with the user community during such a reiteration process is strongly recommended. Time appears to be on the side of training/systems analysts because of the expected improvements in speech recognition technology. If a reduced training system capability is agreed upon, then it should be formally recorded. When the speech recognition technology projection will not meet the system requirements, an agreement may be possible to continue with the training system production with a view to adding speech recognition technology later. Such a decision requires substantial attention to specifying and designing a system that can be retrofitted and still be cost effective.

In addition to the hazards arising from compromising the basic training system design, the training/systems analysts must be aware of three other pitfalls which have their origin in the technology matching process: These are:

1. Underprojection of the technology to meet a specific speech recognition system requirement. This will produce a system with lesser capability than was possible. However, this conservative approach can be relied on to produce a training system which will meet the requirements.

2. Overprojection of the technology to meet the system requirements. This can produce a system where the speech recognition system will not fulfill the design requirements, thus making the training system ineffective.

3. Inappropriate analysis of features requirements may cause the speech recognition system to be too sophisticated or too rudimentary in fulfilling the training requirements.

In conclusion, the output of the matching process should always be a hard YES/NO decision. If the decision is YES, it should be consumated by a training system design requirement document which includes the speech recognition system and is ratified by the user community.

SPEECH SYSTEM OPERATING AND HUMAN FACTORS DESIGN

Once the decision to proceed with system design has been made, it is vitally important to describe exactly how the system will operate. The

level to which this description is made must fulfill the needs of the working level software programming staff as well as the needs of the operational training manager.

Training Scenario Development

The recommended approach is for the training/systems analyst, in conjunction with a subject matter expert, to develop an operating scenario for the overall training system. Each event, including speech, that takes place in the interface between the training device and the trainee (and instructor when applicable) should be described in a step-by-step manner for each part of the scenario. During this process, the analysts will discover a series of human factors design questions which have to be resolved as they arise in order to continue with the operating scenario development. The product of the scenario developed is the preliminary functional design which includes the functions of the speech recognition system. It must be reemphasized that each part of the operating scenario should be in such detail that each software programmer understands what is required of him/her throughout the training system operational picture.

A recommended method for structuring the development of an operating scenario is to partition the operation by modes and submodes. In the case of the LSOTS (McCauley and Cotton, in press)) the system operation was partitioned as follows:

- o Initialize
- o Demonstration
- o Instructional
- o Manual backup
- o Off-line

These modes were then partitioned into submodes as shown in Table A-4. The system operation and the manner in which the trainee interfaces with the system was then described for each submode. For example, in LSOTS the speech recognition test submode can be called on by the trainee and/or the instructor during the instruction, practice, and debrief submodes. Furthermore, during the development of the LSOTS operating scenario, it was decided to introduce a manual backup mode in the event that the speech recognition system would not operate with a particular trainee's voice characteristics.

Human Factors Considerations

Each training system design will require specific human factors considerations which apply to the speech recognition system (see Van Hemel, et al., 1980). However, there are three human factors considerations which are common to all voice interactive training systems and which the training/system analyst must carefully consider. These are:

TABLE A-4. LANDING SIGNAL OFFICER TRAINING SYSTEM MODE CONTROL

Mode/Submode									
Initialize	Performed by Training Device Technician								
Demonstration	Automatic Canned Scenario								
Instructional	Sign-on	Access Records	Select Training	Warm-up/ Review	Instruction/ Teach	OPS- Brief	Practice	Debrief	Sign-off
					Voice Data		Test		
Manual Back-up	Sign-on	Access Records	Select Training	Warm-up/ Review	Instruction/ Teach	OPS- Brief	Practice	Debrief	Sign-off
Offline	Sign-on	Manual Coded Entries Thru External Keyboard							

- o Speech data collection
- o Speech recognition testing
- o Recognition feedback

Speech Data Collection - This is a requirement of speaker-dependent systems. The objective is to collect reference patterns about how each user says each digit/word/phrase in the vocabulary. It is desirable to collect this data in the training context. However, this requires time on the system and if the user population is large and time on the system is short, streamlined data collection procedures may be necessary. If the total time for speech data collection is long, it may be beneficial to do the sampling over several sessions to avoid boredom and voice fatigue. Thus, speech data collection procedures become an important part of the training curriculum.

Current speaker-dependent recognizers require two to ten samples. For a vocabulary of several hundred words, speech sampling can become a time consuming exercise. Notwithstanding that speech consistency is the panacea for successful operation, it may pay to have the speaker introduce some variability in the samples. The range of variability must be traded off against the number of samples to be collected. The introduction of environmental variabilities into data collection may be advisable, but this procedure has similar constraints with the number of samples collected.

Speech Recognition Testing

This feature enables the trainee to determine that the recognition system is working correctly. Testing should be executed as a separate (sub) mode and should reflect the digits/words/phrases that have been sampled. The test mode allows the trainee to speak any vocabulary item (for which a reference pattern has been established) to determine that it is being recognized correctly. The test mode can suggest to the trainee the vocabulary items that the recognition system is having trouble discriminating, and suggest new speech samples to overcome the problem.

Initiation of the recognition test mode can be made by the system, by the trainee or by the instructor. System initiation of the test mode can be designed to occur at the end of a submode when recognition accuracy declines below some threshold.

A CRT terminal is a useful medium for displaying the recognition response to the test utterances. Speech generation is an alternative method to provide feedback information about the recognized item.

Recognition test is a good speech "practice" sub-mode. It allows a new trainee to build confidence that he/she is speaking in a consistent manner. However, unless the vocabulary is small, say under 20 words, random test utterances by the user should give away to a more orderly set of test utterances as determined by the speech recognition system. A confusion matrix is a good way to indicate to the user which digit/word/phrase should be tested (and new speech data collected). The

confusion matrix relates the confusion of each vocabulary term to every other. In the recognition test mode, the user can call for the display of the total matrix or only those utterances which have a high confusion index. A confusion index provides an indicator of the recognition status of the vocabulary items. Based on the confusion index, the user may decide to "retrain" all problem items before continuing. Alternatively, he/she may elect to "retrain" only selected utterances which are interfering with the progress of training.

Speech Recognition Feedback. Speech recognition feeback is a technique of immediate verification after each utterance when the user is not in the test mode. However, the presentation of the recognition feedback must not interfere with the primary training task. Response timing for recognition and feedback display is critical in a fast moving scenario (like LSOTS). A maximum of one second is recommended for feedback for rapidly paced tasks. Design decisions with respect to recognition feedback should focus on making the information available to the trainee without disruption of the training task. Some variables to consider include type of presentation, visual or aural, location of visual presentation, and temporal characteristics (constant parameters or task-dependent).

Normally the feedback message should be presented passively on the primary training display. This is easily accomplished when the display is a CRT. However, where no CRT is used, an alphanumeric display in the main field of viewing activity is a suitable alternative.

Recognition "flagging" is a technique for informing the user that system recognition has taken place, without stating what actually was recognized. This technique is not recommended, because it can mislead the user when the utterance has been recognized incorrectly. It could be a useful technique, however, in systems with very high (99%) recognition accuracy.

A situation display change is an active but indirect way of presenting user feedback. This technique is good, providing that the situation change is consonant with correct recognition, and that the time required for the display change does not delay the pace of the training task. If the delay is too long, it can induce the user to make another, normally more emphatic, utterance to attempt a successful recognition. Unfortunately, more emphasis causes recognition errors and eventual frustration of the user.

SPEECH SYSTEM SPECIFICATION

The speech system specification is normally divided into two parts, recognition and generation. The former is discussed herein. No attempt should be made to develop a speech system specification unless:

1. A list of system requirements has been developed and approved.

2. The match between system requirements and projected technology shows that production of the system is feasible.

3. System operating and human factors design has been completed.

4. Speech features required by other subystem, (like Instructor Model and/or Simulation and Event Control) are properly delineated.

Many specifications are not particularly useful because they are written generically rather than specifically. The generic sense reflects that the writer does not know sufficient detail to be specific at the time of writing. If the generic specification becomes part of a contract then both parties are endangered. It is best to attempt to specify everything and to identify missing details as "TBD" - to be determined.

The structure of the speech recognition specification should be based on the features list shown in Table A-3 and organized hierarchically as proposed in Figure A-3. The document describing the system operating and human factors design should be included as an appendix to the specification. In order for the specification to be a useful document, detailed descriptions are required of how the speech system will operate and its interface with the trainee and/or the human instructors.

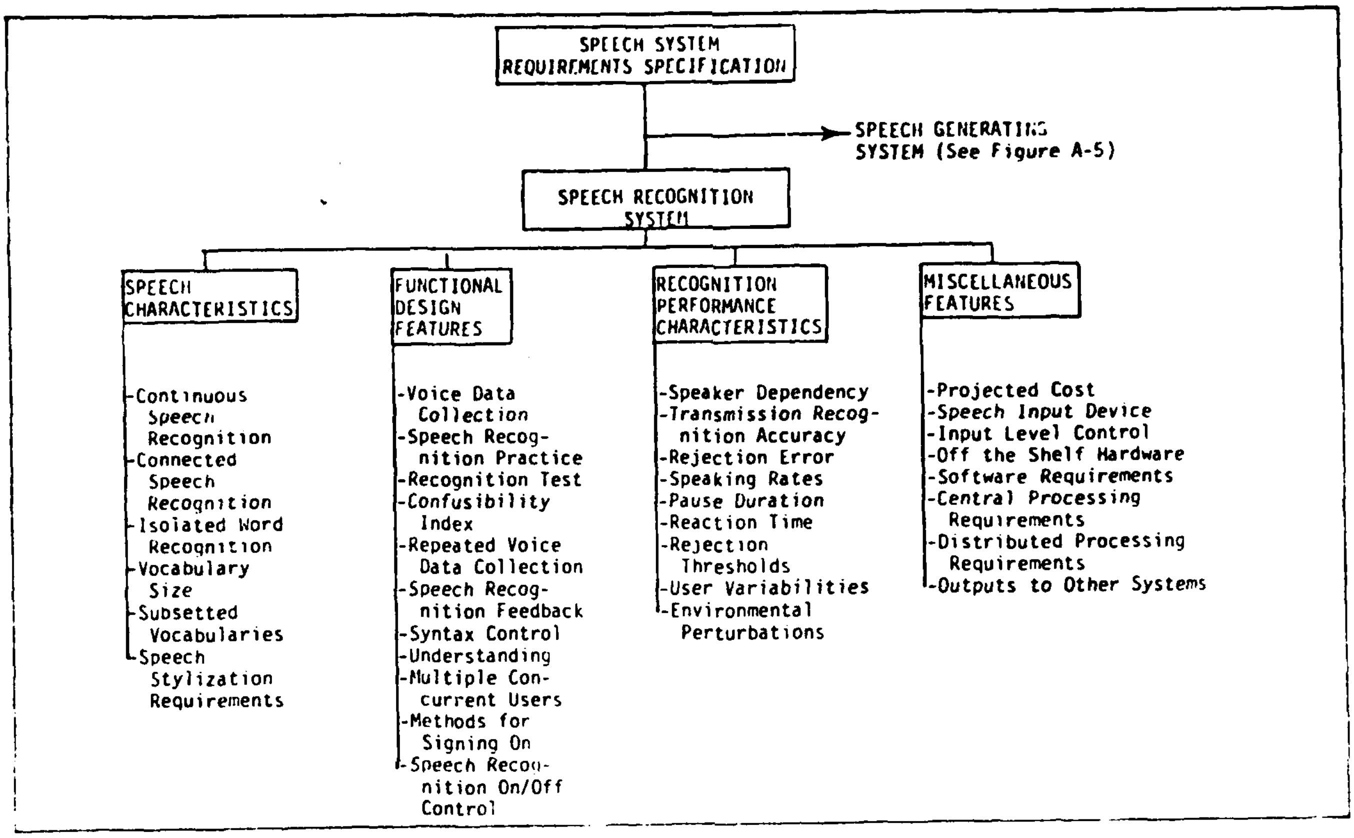

Figure A-3. Speech System Specifications: Recognition System Requirements

DESIGN GUIDELINES

GENERAL APPROACH

Figure A-1 presents a design procedure intended to provide guidance to training/system analysts and systems engineers (the training system design team) on the implementation of an automated speech recognition system to support training.

DEVELOP A SPEECH TRAINING TASK VOCABULARY

Conduct a speech task and vocabulary analysis based on the output of the ISD process.

Identify those utterances spoken by the trainee in the conduct of training.

Identify those utterances spoken by the instructor (or others) to the trainee during the course of training.

Develop a speech task vocabulary which is operationally acceptable and technically feasible.

Identify and document any words and phrases which are expected to be difficult for the system to recognize but which are essential to training.

Identify any speech task time constraints imposed by the conduct of the training scenario.

IDENTIFYING THE SPEECH RECOGNITION SYSTEM REQUIREMENTS

Speech Recognition Characteristics

Select the speech recognition characteristics required of the system in accordance with Table A-3 A. Decide on the type of recognition system which will best meet the training needs: continuous, connected or isolated speech recognition. Decide on the vocabulary size required. To allow for unforeseen expansion, this should be at least 10% larger than the vocabulary size determined from the speech task and vocabulary analysis.

Identify how the vocabulary can be subsetted as a function of the operating environment to enable a higher order processing (understanding) of words and phrases.

Ensure that the user understands the stylization constraints imposed by the recognition system. In particular, pausing constraints should be consistent with the operational language.

DESIGN GUIDELINES

Functional Design

Develop the functional design of the recognition system in accordance with Table A-3 B.

For speaker dependent systems, decide how speech data collection and recollection will be implemented (off-line, special data collection scenario in the training context, transparently in progressive stages, or a combination of techniques).

Identify how and when speech recognition practice is to take place, how recognition testing will be implemented, and how word and phrase recognition confusion data will be presented to the trainee (and human instructor).

Decide how speech recognition feedback information will be presented to the trainee (and human instructor). Ensure that the feedback information does not interfere with the conduct of the training task.

Develop the operational rules and probabilities which govern the use of the task vocabulary so that syntax control logic can be developed to provide a higher order of speech understanding.

If the training system is to be designed for multiple concurrent users state that the speech recognition response for each trainee station will not exceed one second and that each station will operate independently from all other stations. If there is any doubt about the statement, the systems engineer should request a thorough review of the multiple user concept.

Develop the method of signing on for the trainee and human instructor and decide on the use of peripheral devices such as diskettes and high-density magnetic cards. Aspects to be considered are the storage of the user's speech reference patterns, training system access security, and the storage of trainee, instructor and class records. These aspects should be coordinated with the training system administrators.

Determine the optimum method of keying the control of the user inputs to the recognition system.

Recognition Performance Characteristics

Select the speech recognition system performance characterics in accordance with Table A-3 C.

Determine what transmission accuracy and rejection error is acceptable for the system. Everyone would like to see 100% and 0% respectively. However, the operational community can be expected to yield to figures slightly less than perfect. But, it is vital to state that these figures will be obtained in the operational environment using typical trainees.

DESIGN GUIDELINES

Current recognizers will not allow a vocabulary item to exceed 2 - 5 seconds (depending on the manufacturer). Recognition of discrete words can be expected up to rates of 50 words/minute, and possibly as high as 180 words/minute. Current isolated word recognition systems require a minimum pause of 100 milliseconds between words and phrases. Newer techniques are reducing this to less than 50 milliseconds. The recognition system should begin to respond in a manner perceptible to the trainee within 1 second of utterance completion.

An adjustable rejection threshold is recommended. Rejection levels should be adjusted to achieve optimal performance within the context of the training task. The opinions of the user community should be elicited to assist in rejection threshold adjustment.

Major sources of speech variability should be determined, and appropriate countermeasures undertaken. Short term, but consistent voice changes (such as fatigue or a cold) can be countered with an updated temporary speech data collection file. Stress effects should be reduced by any effective means. Examples are to create stress during speech data collection, to provide training on maintaining consistent speech despite stress, or to reduce the stress.

Environmental perturbations should be determined and eliminated whenever possible. Consistent noise may be countered by performing speech data collection with the noise present.

Miscellaneous Features

Develop other features of recognition system in accordance with Table A-3 D.

Be realistic about system cost. Consider whether a stand-alone recognizer is sufficient, or will "understanding" software need to be developed.

A close-talking, noise cancelling microphone is recommended for speech inputs to the recognition system. Hand held devices are less desirable than a headset with boom microphone because they add another source of variability. A high response, automatic gain control input is recommended to enhance consistency of speech input.

DESIGN GUIDELINES

REASSESS THE SPEECH TECHNOLOGY STATE-OF-THE-ART

Speech technology is advancing rapidly. The training systems design team should reassess the state-of-the-art to determine what features and capabilities are available. These capabilities must be matched to the requirements of the speech recognition system.

A list of major features and capabilities is given in Table A-3. This list should be used to aid the technology reassessment. Sources of information should include a review of the most recent recognition systems applications (outside the laboratory), and, with reservations, review of the latest claims made by the manufacturers.

MAKE A SPEECH RECOGNITION TECHNOLOGY PROJECTION

Make the technology projection based on six key points discussed in the previous section under the subheading "Making a Speech Recognition Technology Projection." Do not be concerned (at this stage) whether the available technology does not match the system requirements, so far as they have been defined (see "Matching Technology to System Requirements").

Systematically match the technology to the previously developed system requirements. The performance of some technology may not be up to expectations. Therefore, each match should be given a rating or weighting.

If the technology features will not meet system requirements, then the system requirements may have to be scaled down and the matching process reiterated. Involve the operational community in this reiteration process and document the system requirements agreed upon. Remember you are looking for a yes/no matching answer. But note that over projection of the technology can produce a training system which could be unusable; whereas under projection will produce a useable system that will not necessarily fulfill the operational requirement. (The system designer can be caught either way!)

SPEECH SYSTEM OPERATING AND HUMAN FACTORS DESIGN

As soon as the decision is made to proceed with the system design, describe in detail how the speech recognition and generation systems will operate. The description must fulfill the needs of operational training managers as well as software programming staff so that no operational ambiguities exist.

DESIGN GUIDELINES

Develop a step-by-step operating scenario in conjunction with a subject matter expert. Describe each action which takes place in the interface between the training device and the trainee in as much detail as possible.

Expect to discover a series of questions involving human factors design and operating procedures which have never been addressed before. Try to resolve these questions as they arise, before continuing with the remaining scenario development.

Important human factors considerations for the speech recognition system center on speech data collection, recognition testing, and recognition feedback (see the previous section, subheading "Human Factors Considerations").

Document the system operating and human factors design as the preliminary functional design description.

DEVELOP A SPEECH SYSTEM REQUIREMENTS SPECIFICATION

Document the speech recognition (and generation) system requirements in a specification. The system specification should include the preliminary system functional design document as an attachment.

No attempt should be made to develop a speech system specification unless:

1. A list of system requirements has been agreed upon.

2. The match between system requirements and projected technology indicates that production of the system is feasible.

3. The system operating and human factors design has been completed.

4. The speech features required by other subsystems are properly delineated.

The speech recognition requirement specification should consider the requirements set out in Figure A-2.

PART TWO

SPEECH GENERATION SYSTEMS

INTRODUCTION

This design guide is intended to encompass a design procedure for speech generation (synthesis) systems, as depicted in Figure A-4. The steps in the procedure are as follows:

1. Extend the ISD process to include speech task analysis for a planned training system development endeavor.

2. Identify the speech generation system design requirements from the task analysis.

3. Update a technical projection of the automated speech technology "state-of-the-art" to facilitate a decision about whether the design requirements for the speech generation system can be met.

4. Make the technical projection whether the design requirements for the speech generation system can be met in the time frame in which the training system is required to start operating.

5. Make the planning decision that the speech generation system features can be met within the technical projection for a specified production system time frame.

6. Develop the speech system operating and human factors design so that the operation of the system can be thoroughly described for all personnel involved with the design and development process.

7. Develop the speech system specification so that it becomes an effective document for the designers, developers and users of the training system.

The use of the words "recording and playback" in the foregoing outline presupposes that all communications made to or by the trainee are recorded for each training session and are available to be played back as required.

SPEECH TASK AND VOCABULARY ANALYSIS

The speech task/vocabulary analysis should be conducted concurrently for speech generation and recognition. It is the responsibility of the generation system to provide those utterances normally made by:

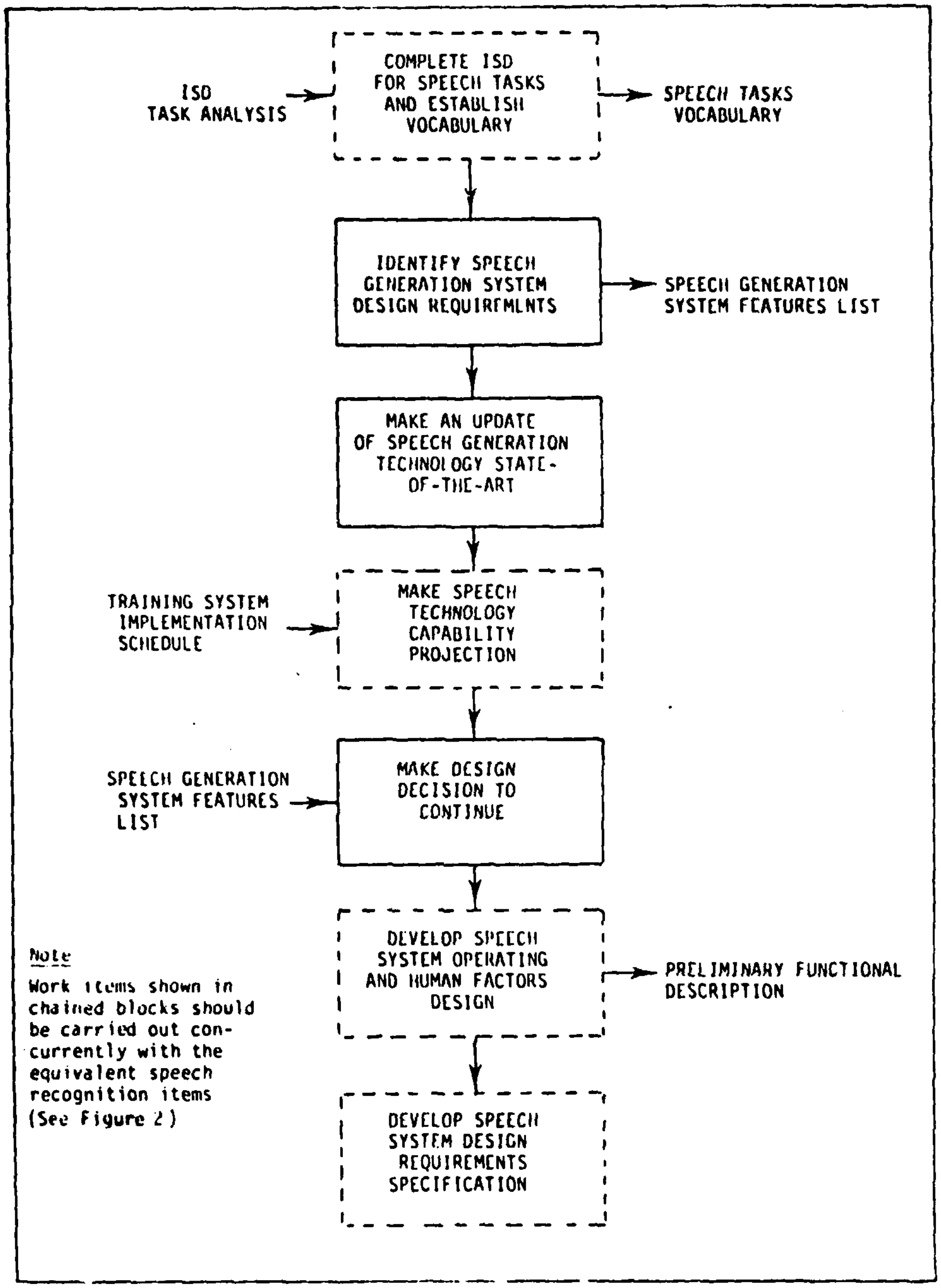

Figure A-4. Work Flow for Speech Generation System Design

1. The automated (psuedo) instructor in the conduct of training.

2. Other persons who transmit verbal information to the trainee during the conduct of the tasks, e.g., pilots, air traffic controllers, tactical coordinators, team members, etc.

3. The training system in the form of cues and prompts which are required to provide instruction to the trainee.

Each simulated speaker should be established with a separate vocabulary of digits/words/phrases to be generated. Where there will be substantial reliance on the spoken word from the training system to instruct the trainee, a basic speech generation vocabulary capacity of 500 words is recommended.

TIME CONSTRAINTS

Time constraints for speech generated messages occur when there are more than one message transmission channel available and when there are multiple messages to be transmitted on each channel.

Generated messages should be automatically overridden when the trainee is speaking, provided that such overriding is in context with the operational environment. Alternatively, the generated message(s) may be allowed to continue but should not interfere with the speech recognition process.

Multiple messages from a different sources can be transmitted to the trainee simultaneously, provided that they are in context with the operational environment.

If more than one message is to be transmitted over one channel to the trainee, the messages should be prioritized. Once each message transmission has commenced, it should not be overridden by a higher prioritized message on the same channel. If the speech generation channel(s) can be overridden by the trainee's transmission, then the partially transmitted message should be repeated in full, provided that such repetition is in context with the training scenario.

Generated speech messages which are used to cue and prompt the trainee for instructional purposes should not be repeated more than twice.

With the foregoing time constraints, it is necessary for the training/system analysts to develop inter- and intra- channel priority schedules for all speech generated message vocabularies.

IDENTIFYING THE SPEECH GENERATION SYSTEMS REQUIREMENTS

The purpose of this step in the development process is to produce a written definition of the requirements for speech generation, recording and

playback. Table A-5 lists the features which should be considered in developing the requirements. The table has been subdivided as follows:

Speech Generation - Requirements which relate to speech messages generated by the training system.

Speech Recording and Playback - Requirements which relate to the recording and playback of utterances made by the trainee, the human instructor (when present) the pseudo instructor and communicate with the trainee during training sessions.

REASSESSING THE SPEECH TECHNOLOGY STATE-OF-THE-ART

The reassessment of technology for speech recognition and generation should be coordinated. Speech generation technology, as applied to voice interactive training systems, has advanced to the point where solid state devices are available to provide 274 words of naturally spoken male speech with integral controls processing for under $100.00.

Both speech generation and recording/playback technology must be assessed and compared to the training system requirements. Both are advancing rapidly, so a useful technology assessment must include projection of the capabilities over the time-frame of the training system development. The recording technology assessment should include the processes of recording, analog to digital conversion, digital compression, and storage in random access solid state or disc-type memories. Access time for a particular part of a recording becomes an important performance criterion.

Each feature should be related in a systematic manner to:

1. The most recent experience gained in the field with speech generation recording and playback.

2. The lastest claims and demonstrations made by manufacturers in regard to a specific generation recording and playback capability.

For the foreseeable future, the use of the "analysis/synthesis" method of speech generation is recommended for all training system applications because it provides more natural speech and speaker variability than the "synthesis-by-rule" mechanization (see Michaelis and Wiggins, 1981).

MAKING A SPEECH GENERATION TECHNOLOGY PROJECTION

Having established the current state-of-technology, the training system design team should have no difficulty in making a projection of where the generation and playback technology is likely to be in the time frame of building the training system.

TABLE A-5. SPEECH GENERATION SYSTEM POTENTIAL REQUIREMENTS

SPEECH GENERATION

Number of channels required

Speaker Identity
Sex, dialect, speaker differences, naturalness

Vocabularies
Number required, size, single digits, coupled digits, words, phrases,

Priorities
By channel, by message type, message repetition protocol

Message Format
Prerecorded, analysis/synthesis, synthesis-by-rule

Output
Type of device, power required, frequency response

SPEECH RECORDING AND PLAYBACK

Number of speech channels to be recorded

Type of recording
Analog, digital,

Storage Medium
Tape, disc, random access memory device

Recording control
Continuous, switch activated, voice activated

Extent of Recording
One training session, "N" training sessions

Playback control
Indexing by time, indexing by event, in combination

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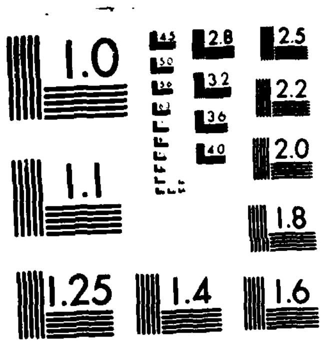

MICROCOPY RESOLUTION TEST CHART
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There are at least six key points on which the speech generation projection should be made:

1. Ultimate size of the vocabulary.

2. Availability of multiple voices.

3. Naturalness of each voice.

4. Unit price.

5. Reliability (MTBF) of integral parts.

6. Internal or external processing and control.

The speech recording and playback projection should include:

1. Ultimate storage capacity for four letter words.

2. Storage medium - integral or external.

3. Analog or digital format.

4. Access time to any part of the recording.

5. Unit price.

6. Reliability (MTBF) of integral parts.

MATCHING TECHNOLOGY TO SYSTEM REQUIREMENTS

Based on the definition of the speech generation system requirements and the technology projection, it will be possible to make a match between them. If there is not a complete match on the first time through, it is most likely than some factors in the system requirement have been overstated or alternatively, the technology has been under assessed. In the near future a substantial reduction is likely in the cost for solid-state, digitally formatted word storage devices. Increased storage capacity is expected during the same time frame. This advancement will be the natural outcome of combining micro processors and cheap bulk memory onto one or two chips. This capability, in turn, will lead to distributed processing for the various functional modules of speech-interactive training systems of the future.

SPEECH GENERATION SYSTEM OPERATING AND HUMAN FACTORS DESIGN

Once the decision to proceed with system design has been made, it is important for the training/system analysts to describe how the generating and playback system will operate. This description should be developed in

concert with the recognition system functional description, described in Part 1, to fulfill the needs of all personnel involved with the training system design and development.

Training Scenario Development

See the discussion in Part 1.

Human Factors Considerations

There are five human factors considerations for speech generation systems that are common to all speech interactive training systems, and should be considered carefully by the training/systems analyst.

1. The naturalness of the generated speech.

2. The timing of the generated output always should be in context with the training scenario.

3. The generated speech response should start within a very short time of the end of a verbal request from the trainee (nominally, one second).

4. For playback, the access to a recorded section of speech should be fast and in sync with the training scenario being represented.

5. When multiple messages are being transmitted over one channel, the messages are prioritized correctly and each message is transmitted in its entirety.

SPEECH SYSTEM SPECIFICATION

The speech system specification is normally divided into two parts, Recognition and Generation. The former is discussed in Part 1 and the latter (which includes speech recording and playback) is discussed herein.

No attempt should be made to develop a speech system specification unless:

1. A list of desired requirements have been developed and approved.

2. The match between system requirements and the technology projection shows that production of the system is feasible.

3. The system operating and human factors design has been completed.

4. The features required in the other subsystems (i.e., Instructor Model and/or the Simulation and Event Control Model) are properly delineated.

The specification for speech generation, recording, and playback should be as specific as possible. This is feasible because the speech generating system requirements (identified in Table A-5), are not complex and, furthermore, the current technology can fulfill nearly any requirement which will arise in the near future. The structure of the speech generation specification should be based on the requirements list shown in Figure A-5. The document that describes the system operating and human factors design should be included as an attachment to the specification. The information about how the speech generation system will operate and how it interfaces with the trainee and/or human instructor must be very detailed for the specification to be a useful document.

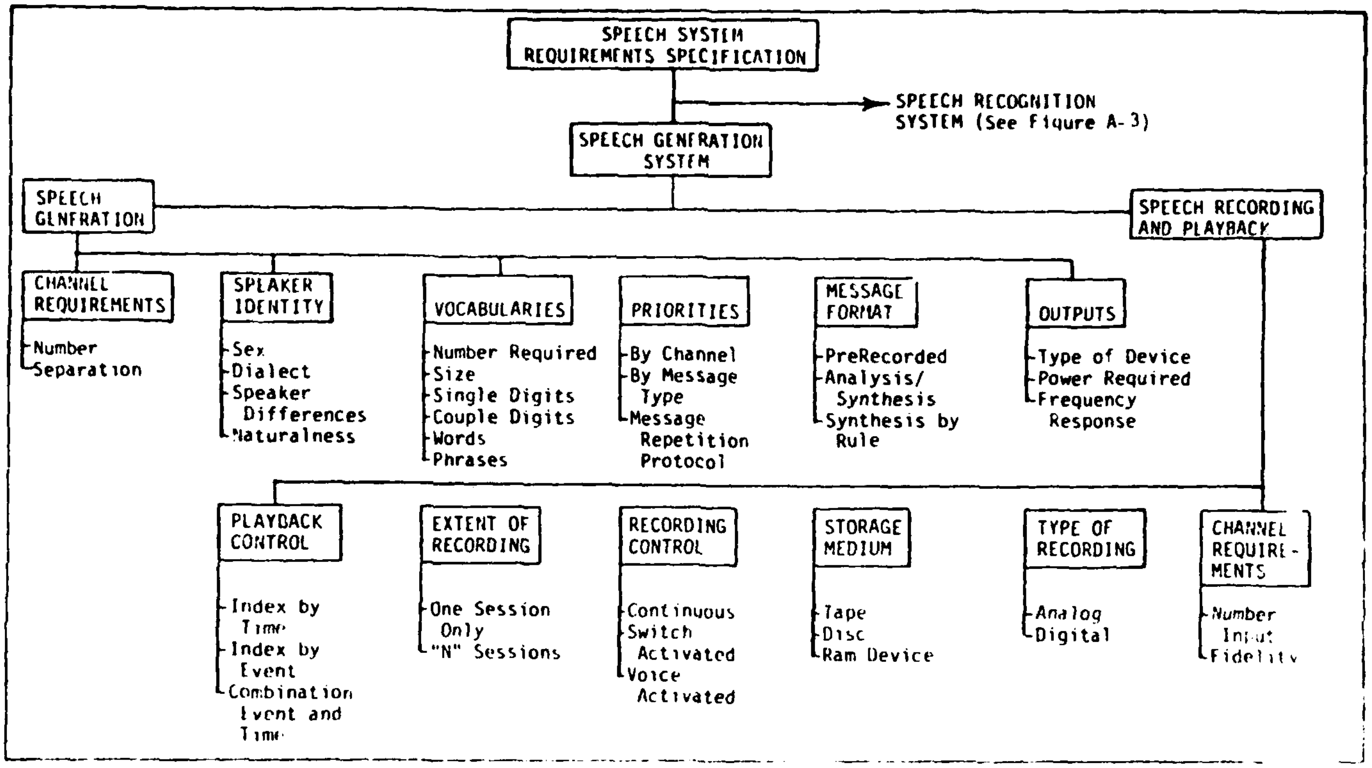

Figure A-5. Speech System Specification: Generating System Requirements

DESIGN GUIDELINES

GENERAL APPROACH

Develop a speech generation system design in accordance with the procedure shown in Figure A-4.

DEFINE THE SPEECH GENERATION SYSTEM REQUIREMENT

Use the checklist in Table A-5 to develop the generation, recording and playback system requirements.

REASSESS THE SPEECH TECHNOLOGY STATE-OF-THE-ART

For speech generation recording and playback, the reassessment for a specific training system should be made concurrently with that for speech recognition. Because the former technology is advancing so quickly, interim reassessment should be made to keep abreast of development.

Make the assessment based on: 1) the most recent experience gained in the field with speech generation, recording and playback; and 2) the latest claims and demonstrations by manufacturers for specific products.

DEFINE THE MESSAGE TIME CONSTRAINTS

Define the number of message transmission channels required between the generation system and the trainee (and human instructor).

Develop the inter- and intra- channel transmission priority protocol.

Define the inter- and intra- channel transmission priority for each word and phrase group.

GENERATE SPEECH VOCABULARIES ANALYSIS

Define the speech generation vocabularies to be used by the various people whose voices are simulated by the system. Examples are an automated instructor, pilots, air traffic controllers, tactical controllers, simulated team members, etc.

Determine the number of different words required by each vocabulary.

DESIGN GUIDELINES

MAKE A SPEECH GENERATION TECHNOLOGY PROJECTION

Make the projection based on the twelve key points discussed in the previous section, under the heading "Making a Speech Generation Technology Projection."

Ensure that integral or external processing and control software is available to fulfill the message protocol and prioritization requirements.

For recording, trade off the cost benefits of an integral storage approach versus the use of an external device (like an analog tape recorder). If high speed playback access is not a training requirement, then a high quality reliable tape recorder may be cost effective.

MATCH THE SYSTEM REQUIREMENTS AND THE TECHNOLOGY PROJECTION

Repeat the process until the requirements match the technology available. Be sure that changes made to the requirements are acceptable to the operational community and their expectations of the speech generation system.

Do not concentrate on the speech recognition matching effort to the detriment of speech generation. The latter is just as important because it is an essential link between the machine and the man.

Make a Go/No Go decision to continue with the speech generating system design based on the outcome of this matching process.

DEVELOP THE SPEECH SYSTEM OPERATING AND HUMAN FACTORS DESIGN

Develop the speech system operating and human factors design for speech generation, recording, and playback. This design task should be accomplished in concert with the design for the speech recognition system.

The training scenario should be developed in as much detail as possible. All personnel, from software programmers to training managers, should be fully informed about what the training system will do in each of it's operating modes. Unanticipated problems should be dealt with immediately. Unsolved problems could be disastrous, should they be neglected.

Ensure that the five human factors considerations discussed in the previous section are acted upon.

Document the interaction between the training scenario and the system operating and human factors design as the preliminary functional design description for the speech system.

DESIGN GUIDELINES

DEVELOP THE SPEECH SYSTEM REQUIREMENT SPECIFICATION

Part 1 of this specification covers the speech recognition system and Part 2 the speech generation system.

Both parts of the speech system specification should be developed only when the following steps have been completed: a list of functional requirements has been developed; there is a match between the requirements and the technology projection; the system operating and human factors design has been completed; and the speech requirements of other training subsystems (Instructor Model, Simulation, and Event Control, etc.) have been properly delineated.

The content of the speech generation specification should cover the system requirements set out in Figure A-4.

A generic type of specification is to be avoided. Be specific and do not hesitate to use "TBD" (to be determined) if the information is unavailable.

APPENDIX B

AUTOMATED INSTRUCTOR MODEL DESIGN GUIDE

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AUTOMATED INSTRUCTOR MODEL DESIGN GUIDE

INTRODUCTION

The design guidelines for the automated instructor model are principally oriented toward an instructor model that will operate with an automated speech system (see Appendix A). However, this may not always be the case. Where departure from the guidelines herein is necessary for a system without automated speech technology, the document is appropriately annotated.

The design guide assumes that the user has a working knowledge of instructor model design and a detailed knowledge of the training task to which it will be applied.

Note that an automated instructor model does not preclude the existence of a human instructor station as part of the training system design.

These design guidelines are intended to encompass the following design procedures as depicted in Figure B-1.

1. Define the degree of automation suitable for the instructor model.
2. Develop the system design strategy which is to be used for accomplishing the training.
3. Develop the curriculum which will fulfill the training strategy.
4. Define the performance and evaluation criteria to be used to measure the performance of the trainee throughout the conduct of training on the training system.
5. Develop the diagnostic schema and model of the trainee(s).
6. Develop the instructional operating and physical design requirements of the instructor model.
7. Update what is known about the instructor model technology state-of-the-art and projecting it into the production time frame of the training system.
8. Make the technical decision that the instructor model can be met within the required time frame.
9. Develop the instructor model operating and human factors design including it's interface with the human instructor.

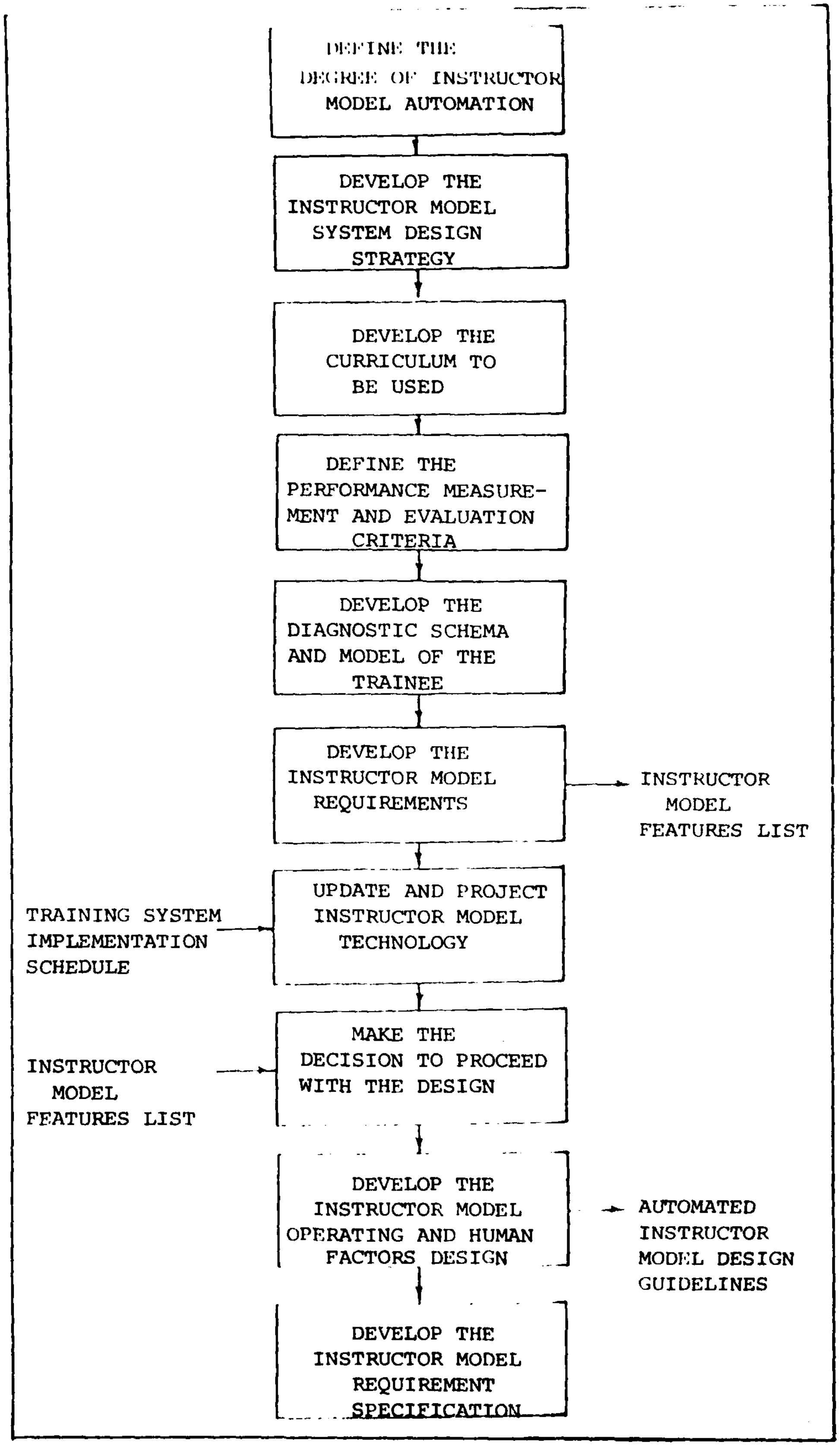

Figure B-1. Automated Instructor Model Design Guidelines

10. Develop the instructor model specification so that it becomes an effective document for the designers, developers, and users of the training system.

In using these design procedures the training/systems analysts and systems engineers should be cognizant that no training system is effective unless it provides accurate and rapid feedback to the trainee as to his or her performance.

DEFINING INSTRUCTOR MODEL AUTOMATION

Before the functional characteristics of an instructor model can be defined, the training system designers must decide on the optimum extent of instructor automation. This decision can be considered as a point on a dimension ranging from no automation to a totally instructorless system. The degree of automation involves many considerations the more important of which are shown in Table B-1. Middle-level automation is described as an instructor support system, in which the instructor still participates actively in every training or event, but some features may be automated to reduce his workload.

Each of these functions may be partially or totally automated. Decisions about the degree of instructor automation should be based on several factors, including:

- Manpower availability
- Manpower costs
- Instructor model development cost
- Relative training effectiveness
- User acceptance and utilization

The desired level of instructor automation must be defined early in the training system design process so that it can serve as a guideline for the development of the instructor model. Decisions about the level of instructor automation also will have an impact on the design of other subsystems, such as voice and simulation/event control. Therefore, decisions about instructor automation must be based on careful analysis of cost, training effectiveness, and user acceptance.

DEVELOPING THE SYSTEM DESIGN STRATEGY

This development is intended to delineate what is required of the Instructor Model to accomplish a specified training course. It is a multi-faceted problem which normally can be solved at a global level.

TABLE B-1. IMPORTANT CONSIDERATIONS FOR AUTOMATED INSTRUCTOR MODELS

TUTORIAL PROCEDURES

- Presentation of Instructional Materials
- General Instructional Approach
- Use of Special Instructional Features

PERFORMANCE ASSESSMENT

- Measurement
- Scoring
- Evaluation
- Diagnostics

PERFORMANCE FEEDBACK

- Knowledge of Results
- Error Description
- Error Reduction Strategies

CURRICULUM CONTROL AND ADAPTIVE LOGIC

- Remediation
- Advancement
- Adjust Problem Difficulty
- Problem Initialization
- Curriculum Branching

RECORD KEEPING

- Progress in Curriculum
- Detailed Performance Evaluations
- Performance Summaries
- Diagnostics Record

TRAINEE MODEL

- Learning Models
- Optimization Techniques
- Resource Allocation
- Validation

However, in some circumstances it will require a prior detailed knowledge of interfacing equipment before any strategy can be addressed.

The degree of simplicity (or sophistication) of the Instructor Model is highly dependent on the operational community's view of what is required of the overall training system. For instance, if the operational task to be trained is like air intercept control, the instructor model may be required to provide automated instruction, curriculum control, performance measurement and evaluation, instruction, practice exercises and record keeping. On the other hand, if the instructor model is to be added to an existing trainer, say, for night carrier landing practice, automation may only be necessary to provide briefing instructions for a series of canned approaches and performance measurement of the pilot.

The strategy is developed by analyzing the operational training requirements and trying to arrive at a top level system solution. A good way to express the system solution is in a block diagram. An example is shown in Figure B-2. Each interconnecting line between blocks should be identified with the information expected to flow along it. An organization for this task is shown in Table B-2.

In those cases where the instructor model will interface with existing equipment, like an operational flight trainer, the training/systems analysts will need the services of a simulator design engineer to determine the input/output information flow available to the instructor model. This step must be accomplished before the instructor model design strategy can be completed (and in some cases, before making the decision whether the operational training requirements can be met at all).

To assist in the development strategy, each training requirement should be analyzed from the aspects of:

1. Modes required to fulfill each requirement.

2. The interfaces required with the trainee (and the human instructor) to provide the flow of training information.

A framework for conducting the the analysis is shown in Table B-3.

DEVELOPING THE CURRICULUM

Curriculum development is a critical step in the development of an effective training system. Experts in training, psychology, and/or instructional technology should be tasked with curriculum organization and development. It is beyond the scope of the present report to discuss this process in detail. Generally, the ISD process should be followed to define the curriculum organization, course syllabi, and behavioral objectives (Branson et al, 1975; Funaro and Mulligan, 1978; Mulligan and Funaro, 1979; and MIL-T-29053A(TD), 1979).

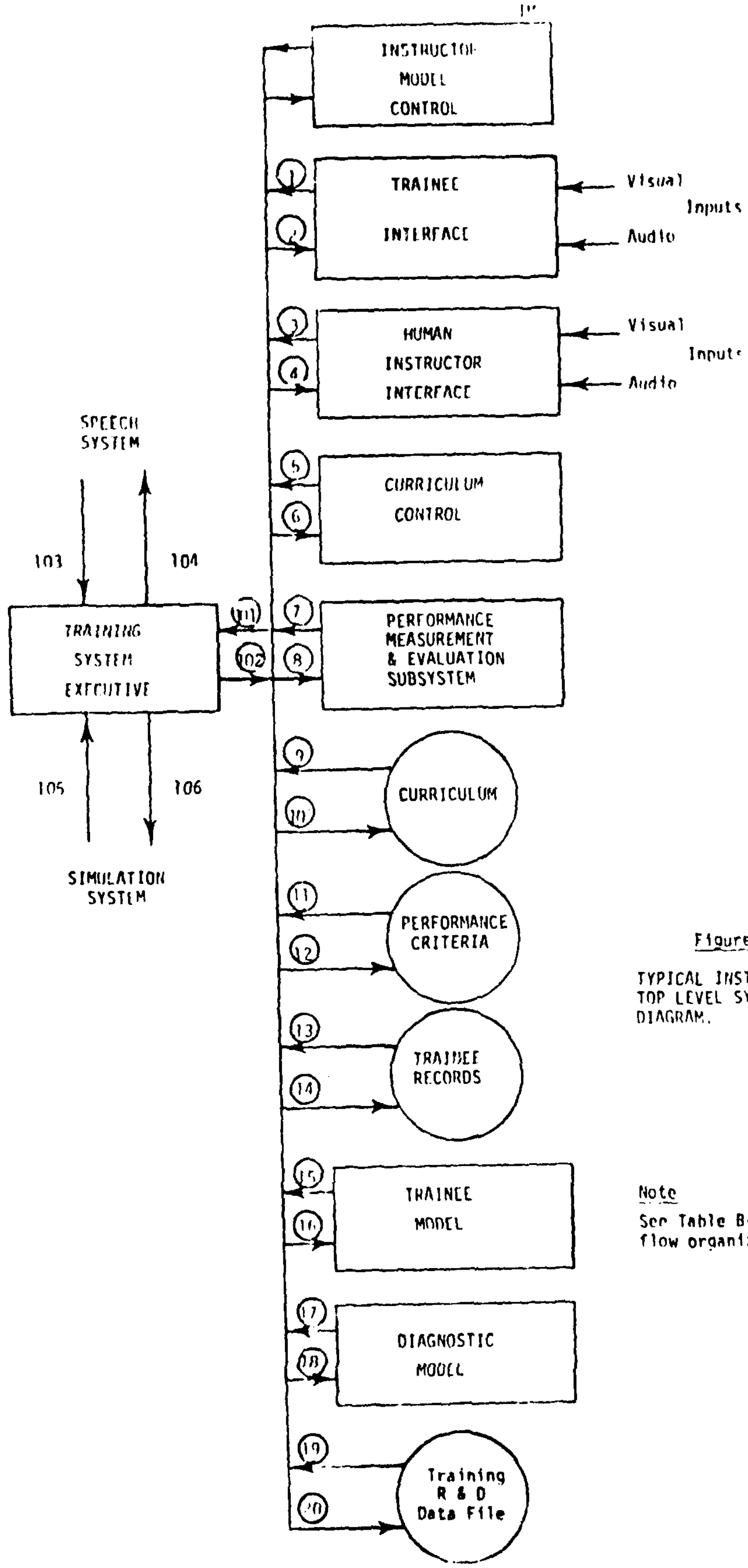

Figure B-2

TYPICAL INSTRUCTOR MODEL. TOP LEVEL SYSTEM BLOCK DIAGRAM.

Note

See Table B-2 for information flow organization.

TABLE B-2. TOP LEVEL SYSTEM INFORMATION FLOW ORGANIZATION

MODEL ELEMENT	INFORMATION	DATA ROUTING	EXECUTIVE CONTROL
INSTRUCTOR MODEL OUTPUT	SIGN ON TO SYSTEM	1 14	IMC
	REQUEST PLAYBACK OF LAST EXERCISE	1 101 106	IMC to TSE
TRAINEE MODEL INPUT	PERFORMANCE OF CLASS ON TRAINING MODULES X thru Y	15 14	IMC
TRAINEE MODEL	AVERAGE PERFORMANCE OF ALL TRAINEE'S ON MODULE Z	15 20	IMC

NOTE: See Figure B-2 for Top Level System Block Diagram
IMC = Instructor Model Control
TSE = Training System Executive (Control)

TABLE B-3. A FRAMEWORK FOR DEVELOPING INSTRUCTOR MODEL DESIGNS

<u>MODES</u>

- Signing on (and off)
- Accessing Records
- Selection of Training
- Review of Previous Training
- Instruction (or teaching)
- Exercise Practice
- Playback of Exercises
- Debriefing

<u>INTERFACES</u>

- Audibly with the trainee
  - with the human instructor (when present)
- Visually with the trainee
  - with the human instructor
- Manually with the trainee
  - with the human instructor

Strong interaction with the user community is necessary throughout the curriculum development. A subject matter expert, ideally, should be an integral part of the process. The curriculum should be partitioned into manageable units to facilitate development of the courseware. The partitioning also will enable subsequent changes in the curriculum to be managed without undue time and cost.

The flexibility of the system to change with changing fleet requirements should be a system design goal from the outset. The system design team must plan for change in the curriculum or the large investments in software/courseware will render the system condemned to obsolescence before it is delivered. A modular approach is highly recommended for curriculum development and its eventual representation in courseware.

DEFINING THE PERFORMANCE MEASUREMENT AND EVALUATION (PM&E) CRITERIA

Criterion-based training performance is fundamental to the design of instructor models. In an adaptive system, the measurement and evaluation of trainee performance can be used to control several aspects of training including position in the syllabus, level of difficulty, and time in training.

It must be stressed that the PM&E criteria must be defined explicity early in the design process. Failure to do so may produce later design deficiencies which could be disastrous to the eventual success of the program.

For voice interactive training systems, speech recognition adds another dimension to performance measurement which the training/systems analysts must consider. In this case, utterances from the trainee contain measureable data. Consider the expression "turn left heading 270." The words "left" and "270" are data on which the air traffic controller performance can be measured. Failure of the speech system to recognize properly makes it impossible for the performance measurement to be accurate, irrespective of how well the performance criteria have been defined.

Automation of the instructor function requires that PM&E criteria be quantified. In most training situations the human instructor uses a mixture of subjective and objective measures to evaluate a trainee. For this design task, each subjective measure should be documented at each stage of training and translated into quantifiable information. Furthermore, objective data already used by human instructors should be scrutinized for source and accuracy before it is accepted as bonafied quantative information.

If the training and systems analysts cannot accomplish this step, the efficiency of using an instructor model for PM&E should be critically questioned. It is better to state that the human instructor could do a better job than the instructor model PM&E design can be expected to provide.

One of the principles of ISD is that it is directed towards criterion performance based training. However, such information is often too global and insufficienctly systematic to lead to the generation of an instructor model software program.

For a successful PM&E system to emerge, the curriculum already must be described in detail so that the satisfactory performance for each key concept and training objective can be quantified.

An example of the PM&E analysis process is depicted in Figure B-3. Perception of the aircraft position in space (line-up and glide slope) is a key concept to be mastered in LSO training. Training for the development of line-up perception involves estimation of lateral position and rate by the LSO. For lateral position, displacement criteria from flight path centerline need to be established for the LSO calls of:

"Check Your Line-Up" ($\pm$ 1/2^o from centerline)

"Little Left/Right For Line-Up" ($\pm$ 1^o from centerline)

"Right/Left For Line-Up" ($\pm$ 2^o from centerline)

(These are examples only. See McCauley and Borden, in press, for detail of LSO modeling).

Establishing the criteria often will require multiple opinions of subject matter experts. Variability in these opinions is to be expected. Some type of consensus should be sought, but, in some instances, it is necessary to collect data in the operational environment or analyze actual operational data to arrive at the criteria. Both can be costly.

In some circumstances, quantative data are available in discrete form (0 or 1) that the trainee accomplishes a specific task, e.g., lowering landing gear. However, while the discrete event is very amenable for PM&E, other circumstances must be considered which describe the timing of the event, like landing gear down at < 1500 & > 100 foot altitude.

When the quantification process has been completed the extent of the measurement task should be assessed and documented. The training and systems analysts should decide on a measurement philosophy that is commensurate with the size of the task and the computing resources that are likely to be available.

Two measurement methods prevail, "collect everything" and "measure by rules." The first method is to measure and record all continuous variables and events throughout each training session and select only those measures which are specifically needed for a particular lesson, event, or sequence. This method provides most flexibility for subsequent modification, if measurement difficulties are encountered in the field. However, the

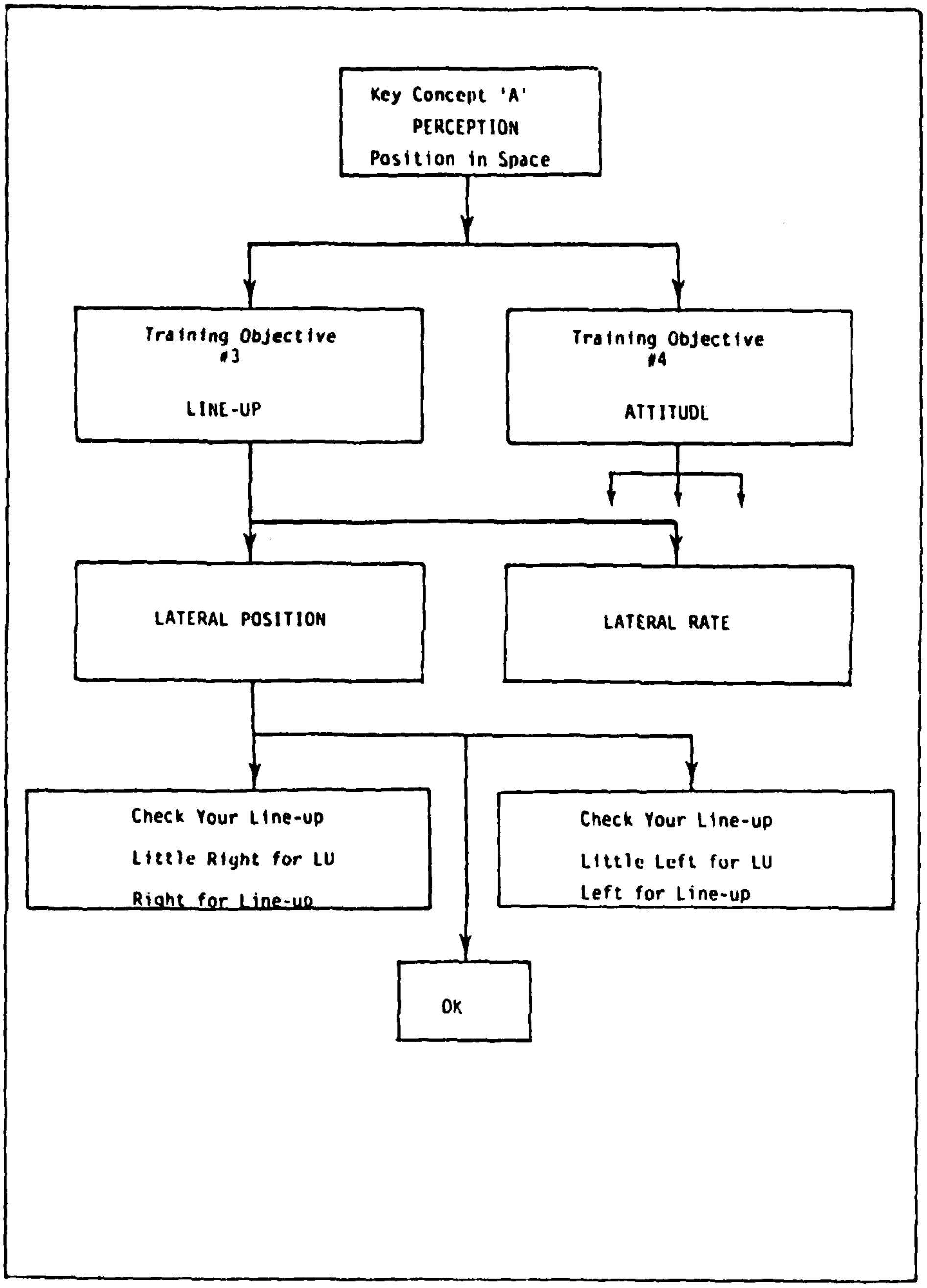

Figure B-3. Scheme for Delineating Performance Criteria for LSO Perception Training

requirements for temporary storage of continuously variable data can be large. The second method is to measure only those variables and events which are specified for a particular lesson, event or sequence. The logical control for this method, however, is more complicated.

The "collect everything" method is most suited to application where there are only a small number of continuous variables to be measured; and/or there is measurement uncertainty at the design stage which will have to be overcome later by field experience. The "measure by rules" is most suited to measuring a large number of variables at specifically defineable events or times, and when the rules can be established early in the design process.

A model to convert the various performance measurements into an evaulation score of the trainee should be developed concurrently with developing the actual performance criteria. The model must be developed through the valuable services of experienced instructors. Normally the analysts can develop a simple algorithm that can be used to demonstrate scoring to the instructors. However, instructors tend to make allowances for subjective variables like "good attitude." The inability of automated measurement to account for such variables may precipitate adverse criticism of the scoring algorithm. There is no guideline to accommodate this type of subjectivity in automated performance measurement.

DEVELOPING THE DIAGNOSTIC SCHEMA AND MODEL OF THE TRAINEE

Diagnosis of the trainee's performance over a series of training sessions is intended to determine when remediation is required for the trainee. This can be accomplished by adapting the syllabus to fulfill the remediation needs, or, if the syllabus is completely linear, by providing special training off to the side of the curriculum flow. Both techniques require knowledge of how the typical trainee performs at each point of progression through the training course.

The use of trainee models and diagnostic models are sometimes considered by the uninformed to be of dubious value because they are difficult to program and their effectiveness is largely unproven. However, they have the potential of providing the highest efficiency for automated training. To achieve this efficiency, continuous in-service expansion of the diagnostics and trainee models must be provided before any benefits can be obtained.

Provision can be made during the design so that both models will continuously adapt by "experience" and optimize themselves.

Optimization techniques for automated adaptive training systems have been described by Chatfield and Gidcumb (1977). Trainee models and optimization techniques for adaptive training can be considered a form of artifical intelligence (AI). The application of AI techniques for voice-based

training systems is currently under investigation by NAVTRAEQUIPCEN, and one study in the program has been completed recently (Chatfield, Klein, and Coons, 1981).

Diagnostic and trainee models should be included from the inception of training system design, irrespective of how rudimentary these models may be. Initially, the output of the models should neither alter the curriculum followed by the trainee nor provide diagnostics. Only qualified instructors and analysts would have access to the information to support further development of the models.

In principle, the initial diagnostic model should be predicated on an expansion of the scheme shown in Figure B-3. For example, the diagnostic model for the LSOTS should be designed to consider repeated instances where either line-up or glide-slope performance is mediocre at ranges beyond 1/2 mile. Initially this might be diagnosed as "poor distance perception." The diagnostic would automatically look at whether the mediocre performance was related to day or night approaches, by type of airplane, whether the perception difficulty had a lateral or vertical flight path preponderance, and make remedial recommendations accordingly.

In principle, the initial trainee model should be designed using a model of the trainee performance based on subject matter expert opinion. This early model should depict the average trainee performance for the accomplishment of key concepts and training objectives as a function of time-in-training. When a sufficient number of trainees had completed their training, the model would automatically modify itself to reflect their performance.

Provisions should be made in the instructor model design to permit combining the outputs of the diagnostic and trainee models. This enables the diagnosis for a specific trainee to be based on the average which is represented by the updated trainee model. Only when the diagnostic and trainee models are adapting themselves satisfactorily should an adaptive training curriculum be considered.

In conclusion it is essential that the training system design team plan for the adaptive process early in the training system design.

DEVELOPING THE INSTRUCTOR MODEL DESIGN REQUIREMENTS

In order to eventually specify what is required of the instructor model three categories of requirements should be developed. These are:

> Instructional Requirements - those features which relate to the curriculum and its control, performance measurement and evaluation, trainee modeling and diagnostics.
>
> Operating Requirements - those features which relate to how the system will operate; modeling, playback, freeze, record keeping, etc.

Physical Requirements - those features which relate to the physical design of the trainee's and human instructor's stations.

A list of each feature which should be considered in developing the design requirement is shown in Table B-4.

Curriculum Structure - requirements should be based on the need for one instruction path which all trainees must follow, or, alternatively, where there are several curriculum paths, the requirements should be based on the ability and learning requirements of the individual trainee.

Curriculum Control - requirements should be based on the need for manual or automatic selection of the next training module to be presented to the trainee. If the control is manual, the trainee or human instructor will make the selection. If the control is automatic, the selection will be based on the trainee's past performance and the training objective to be attained. If the trainee or instructor can disapprove of the automatic selection then an override and reselection capability is required.

Curriculum adaptation for a one path curriculum structure is normally linear. In this case selection of the next training module in the sequence is made dependent on the trainee's performance for the last module.

Curriculum control can be non-linearly adaptive if a multiple path, criterion-based branching curriculum structure is available. Presentation of the next training module will depend on the trainee's past performance and higher order solution provided by the trainee model and diagnostic model. Adaptive curriculum control usually is designed to vary the degree of problem difficulty.

Curriculum Organization - requirements should be based on the need for modular lessons or blocks which relate to a specific training objective. The modular approach is preferred because of the ease with which a module can be changed.

Information defining the training scenario should be stored as an integral part of each lesson module. This information is needed for the simulation and event control model (see Appendix C).

PM&E Requirements - should consider whether the PM&E subsystem will be automatic or manual or both. If manual is specified, then the presence of a human instructor is required.

Behavior to be Measured - requirements should be based on the definition of each variable and/or discrete event to be measured during the conduct of each lesson or during a group of lessons which are related to a specific training objective.

TABLE B-4. INSTRUCTOR MODEL POTENTIAL DESIGN REQUIREMENTS

INSTRUCTIONAL

Curriculum Structure

Single path, multiple path

Curriculum Control

Manual, automatic, instructor/trainee override
linear adaptive, non linear adaptive (branching),
forward/backward jumping, difficulty adaptive

Curriculum Organization

Modular lessons

Block of lessons for each training objective

Ease of addition subtraction and structural modification

Integral scenario requirements

PM&E Requirements

Manual, automatic, criteria

Behavior to be Measured

Common definition for each training objective, defined by each lesson plan

Measurement Type

Continuous measurement of selected variables

Discrete events related to time

Discrete events related to the sequence of other events

Transposition through another system
(like speech recognition)

(Continued)

TABLE B-4. (Continued)

Measurement Units, Transforms and Algorithms

- Continuous variables of different dimensions
- Specific events (non dimensional)
- Time to complete tasks
- Comparison to criteria performance
- Translation to score(s)

Trainee Model

- Rudimentary, expandable, transparent, active

Diagnostic Model

- Rudimentary, expandable, transparant active

<u>OPERATING</u>

Moding (on-line)

- Start up/close down
- Sign on/sign off
- Review trainees past performance/select training
- Review previous training/instruction
- Practice/playback
- Speech training/speech test (voice interactive systems only)

(Continued)

TABLE B-4. (Continued)

Moding (off-line)
Trainee(s) record review
Lesson content review
Trainee model research
Diagnostic model research
Software review and modify
Records
Short term performance (on CRT)
Last exercise performance
Last session performance
Overall curriculum performance
Prior training
Operational experience
Class performance
PHYSICAL
Trainee's Station Layout
Operational equipment and controls
Non-operational equipment and controls
Instructor's Station Layout (if required)
Operational Equipment and controls

Measurement Type Requirements - two measurement philosophies prevail: 1) measure everything all the time and select the data for the measures required by a specific lesson performance evaluation algorithm or; 2) measure only those variables and events required by the algorithm when they occur. The former requires minimal control logic and should be used when only a few common variables and events are to be measured throughout the curriculum. The latter requires substantial control logic and should be used when there are many different variables and events which must be measured throughout the curriculum.

Performance measurement in speech interactive training system performance measurement will be based on the logic representation of recognized trainee utterances. They are time-related discrete events which can contain variable measurement data, "Turn Left Heading 270." Left is a discrete piece of information and 270 can be considered as the value of a variable (heading).

Measurement Units, Transforms and Algorithms - requirements should cover the mathematical requirements of performance measurement. Commonly used measurement units like knots, degrees, etc. should be maintained throughout the training system design. Common transforms like root mean square, and absolute average, are required to manage the continuous variable data. Algorithms are required to transform the measurement data into evaluation scores.

Trainee Model - requirements should be included from the design inception. Most models will start with a rudimentary mechanization based on a qualitive expection of the average trainee's performance. The model should be adaptively expandable as it gathers information about the performance of actual trainees on the training system. This adaptive development should be transparent to the trainees until the trainee model is judged as being reliable, then it can be used in the diagnosis of future trainee performance.

Diagnostic Model - requirements should be included from the design inception. Most models will start with a rudimentary mechanization based on the development of simple diagnostic messages which relate to difficulty in attaining specific training objectives. The model should be adaptively expandable based on data about the interrelated difficulties encountered in attaining specific training objectives. This adaptive development should be transparent to the trainee until the diagnostic model is judged as being reliable, and then it can be used in the diagnosis of future trainee performance.

Moding (on-line) - requirements should be based on the overall training strategy arrived at by the training/systems analyst with the operational training community. Back up modes should be included where new technology will incur the risk of excessive training system down-time.

Moding (off-line) - requirements should cover the needs to: 1) access individual trainee and class records; 2) review the curriculum in terms of structure, lesson content and scenario requirements; 3) conduct analysis for the trainee and diagnostic models; and 4) review, make changes to, and edit the training systems unique software (by qualified individuals).

Trainee's Station Layout - requirements should describe the equipment necessary to interface the trainee with the training system. Facsimilies of actual operational equipment may be used to provide operational realism.

Instructor's Station Layout - requirements should describe the equipment necessary to interface the human instructor with the training system. The requirements may be divided into manual, visual, and audio functions.

IMPLEMENTING AN INSTRUCTOR MODEL TECHNOLOGY UPDATE AND PROJECTION

The purpose of this step in the development of the Instructor Model is: 1) to gain information for application to a specific instructor model, based on the status of other automated instructor models; and 2) to project this information into the production time frame for the training system under consideration.

Descriptive documentation is not sufficient to provide a state-of-the-art technology update for the complicated systems as discussed herein. Training/systems analysts also require hands-on experience with the training systems for an effective update to occur. The following technology features should be observed in other systems:

1. Curriculum structure and its ability to be changed easily.

2. Approach to performance measurement and evaluation, especially the methods used to develop the criteria.

3. Development of higher order models for diagnosis and trainee modeling.

4. Other novel features like the use of personalized magnetic cards for sign-on and records.

The projection of instructor model technology into the future should consider what features are available now and what is being designed for utilization in, say, three years.

For example, the presentation of instructional material is being revolutionized by large volume video discs. But the cost is high. In a three year projection, the analysts might find that the unit cost could reduce by 90%, and even though material training cost will rise by 50%, the use of video disc still will be very cost effective.

Each of the considerations for the updating and projection of technology for a specific instructor model should be carefully documented for future reference.

DECIDING TO PROCEED WITH THE DESIGN

The decision process should be predicated on whether the projected instructor model technology will support a specific model's requirements. Each documented requirement should be examined in this regard. Uncertainties about technological sufficiency should be related to their overall impact on the training system and discussed with the operational training community to determine alternative solutions. An example is the uncertainty of meeting a training requirement for a system with multiple trainee stations using one instructor model. The outcome could be a decision to design the system on a modular basis using a distributed processing concept, starting off with two trainee stations and adding more when the system bugs are resolved.

Time is on the side of the training/system analysts when confronted with a decision on a technological uncertainty. An application of this experience would be inclusion of the trainee and diagnostic models in a passive role as a requirement pending further research on this facet of instructional technology.

The resulting final design requirements should be reviewed by the operational training community and should be documented in detail for future reference. (See "Develop the Instructor Model Requirement Specification.")

DEVELOPING THE INSTRUCTOR MODEL OPERATING AND HUMAN FACTOR DESIGN

Once the decision to proceed with the Instructor Model design has been made, the functional operating and human factors design should be described in detail. The resultant document will become the preliminary functional description.

It is essential that this description be of sufficient breadth and depth so that it meets the requirements of training managers fulfilling the detailed needs of the software programmers.

Seven significant subjects should be covered in the description. These are:

1. The curriculum structure and details of each lesson therein.

2. The performance measurements and evaluations which will be made during the conduct of each lesson.

3. The scenario content for each lesson (see the Simulation and Event Control Model Design Guide in Appendix C).

4. The manner in which information, instruction, proficiency testing, and feedback will be presented to the trainee during all on-line operating modes.

5. The file structure and content format of all trainee, class and instructor records.

6. The interface requirements with other training system models and elements.

7. The operation of equipment and controls at the trainee's and instructor's stations.

It is recommend that these seven subjects be addressed in the context of working through typical training scenarios from the time the trainee (and instructor) sign-on to the system to sign-off.

The functional design is an exacting process that can be expected to reveal new instructional and human factors problems. No problem should be exempted due to difficulty. Each must be resolved in a timely manner. The continuous use of operational training experts normally is essential for a functional development envisaged by this guideline.

DEVELOPING THE INSTRUCTOR MODEL REQUIREMENT SPECIFICATION

This specification is the culmination of the preliminary design process and should be predicated on the agreed to design requirements for the instructor model and the preliminary functional description.

An organization for the specification is shown in Figure B-4. The preliminary functional description should be added as an attachment thereto. Furthermore, the specification should not be written for a general instructor model; it should specifically address every known aspect of the model under consideration.

Generic treatment of specifications often is resorted to when the writers do not fully understand the subject matter and/or do not recognize when details are required. This practice can cause problems when the specification becomes part of a contract. For details which are unavailable at the time the specification is written, it is prudent to use the notation "TBD" (to be determined) and then to make the "determinations" part of the contract.

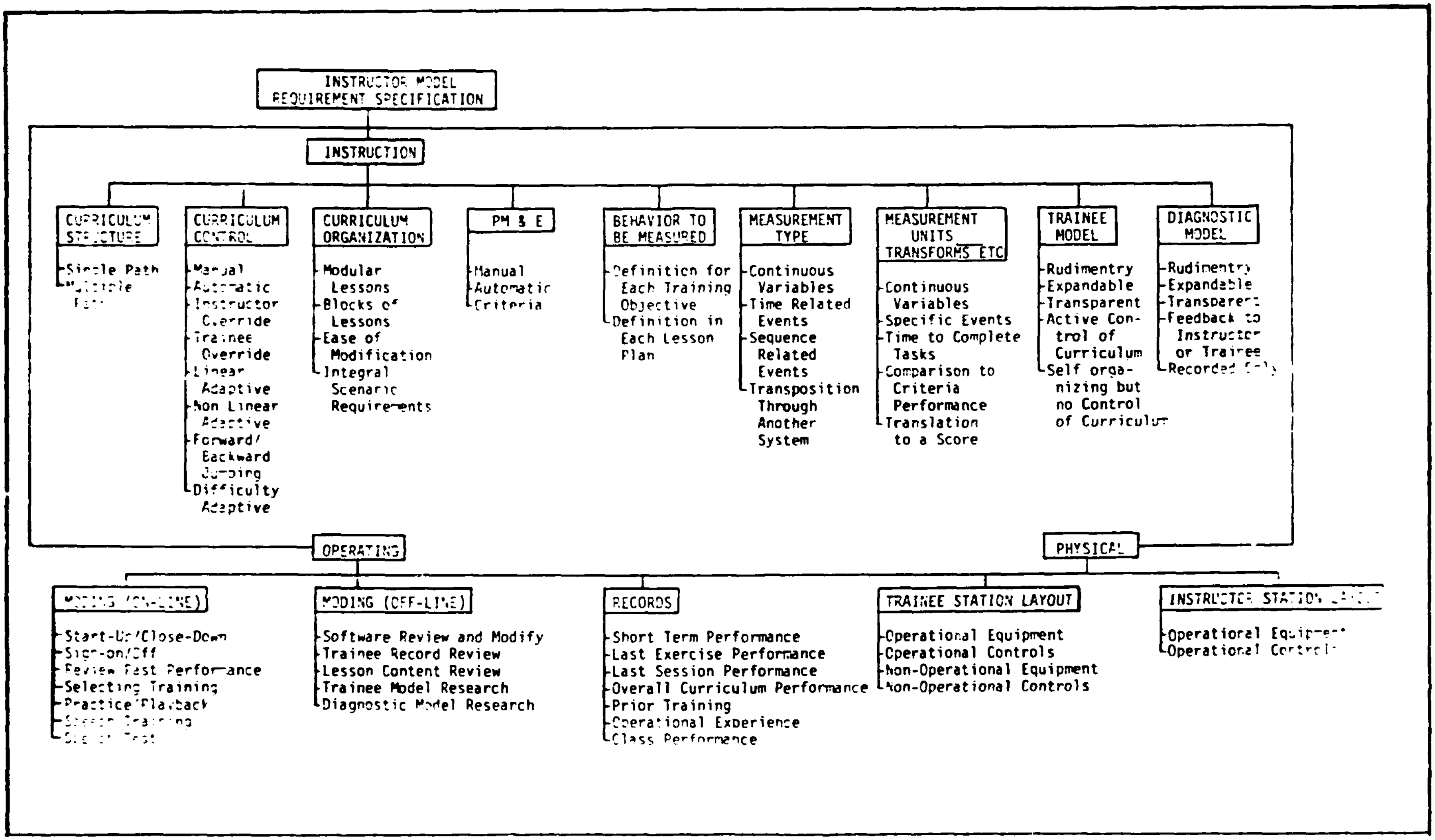

Figure B-4. Instructor Model Requirement Specification Organization

DESIGN GUIDELINES

GENERAL APPROACH

Figure B-1 presents a design procedure intended to provide guidance to training/systems analysts and systems engineers (the training system design team) on the implementation of an Automated Instructor Model to support training.

DEFINE THE DEGREE OF AUTOMATION OF THE MODEL

Decide on the extent of instructor automation which is suited to the training tasks and training system being considered. Points which should be considered are:

1. Instructor functions suited to automation.

2. Instructor model development cost.

3. Instructor manpower availability and cost.

4. Relative training effectiveness of the automation.

5. User acceptance and utilization.

Define the degree of instructor automation early in the design process. This is important because of the impact on the other models and subsystems of the training system.

DEVELOP THE SYSTEM DESIGN STRATEGY

Develop a system design for the instructor model to accomplish a specified course of training by working through each training requirement to arrive at a top level system solution.

Develop a series of block diagrams which cover the major elements of the instructor model, tabulating the information which must flow internally between the blocks and interfacing systems.

Where interfacing equipment is involved, ensure that the required information flow to and from the instructor model is available and in a manageable format.

Define the modes required to fulfill each training requirement and the manual, visual, audio interfaces between the instructor model, the trainee, and the human instructor (when required).

DESIGN GUIDELINES

DEVELOP THE CURRICULUM

Use the best possible subject matter and instructional technology expertise to help in the development of the curriculum.

Follow the ISD process to define curriculum organization, course syllabi and behavioral objectives.

Partition the curriculum into manageable modules to facilitate courseware development and any subsequent changes.

Keep up with changes in fleet training which could affect the curriculum content prior to the training system entering into service.

DEFINE THE PERFORMANCE MEASUREMENT AND EVALUATION CRITERIA

Define the performance measurement and evaluation criteria which will be used to measure the performance of the trainee throughout the conduct of his/her training on the training system.

Define the parameters to be measured in each lesson module including continuous variables, discrete events and their sequences.

Using subject matter experts, quantify each parameter for varying levels of trainee performance expected during each lesson or sequence of events.

Decide on a measurement philosophy. You can measure everything and extract the selected parameters for a particular lesson or sequence; or you can measure only the parameters which are specifically needed for a particular lesson, event, or sequence.

Using subject matter experts, develop a series of performance evaluation algoritihms concurrently with obtaining the performance measurement criteria for each lesson or sequence of events.

DEVELOP THE MODEL OF THE TRAINEE AND DIAGNOSTIC SCHEME

Develop two adaptive models, one which defines the performance of the average trainee as a function of time-in-training; the second which will provide simple diagnosis of performance achievement of training objectives.

DESIGN GUIDELINES

Design these models to accumulate data based on actual trainee performance. Initially, neither model should have any effect on the conduct of training or the assessment of the trainee. The models should be designed to interact appropriately, and to optimize their functions as trainee data become available.

Make provision in the design for recording the adaptation process so that it can be reviewed in the off-line mode.

DEVELOP THE INSTRUCTOR MODEL DESIGN REQUIREMENTS

Develop a set of specific system design requirements based on the potential requirements listed in Table B-4.

Document each requirement using a format such that it may be evaluated in terms of available technology. (See also "Implement an Instructor Model Technology Update and Projection.")

UPDATE AND PROJECT INSTRUCTOR MODEL TECHNOLOGY

Relate each instructor model design requirement to the technology available to fulfill it. Take into consideration the training system production time frame.

Witness the operation of training systems which use automated instructor model technology to gain first hand experience of their performance. Investigate other instructor models which are in the design and development stage. Integrate the information obtained by these two techniques into a technology projection.

Evaluate other advancing technologies which have the potential of fulfilling the instructor model design requirements. Look into its success in other applications and weight your findings accordingly and draw conclusions as to its viability for this specific training system.

DECIDE TO PROCEED WITH THE DESIGN

Make a decision to proceed (or not) based on the outcome of the analysis of matching the requirements with the available technology.

Where the answer is not clear, the operational training community can help to evaluate alternative training strategies that will fit within the technology expectation of the production time frame.

DESIGN GUIDELINES

Reiterate the design requirements until there is a feasible match between the operational training needs and what the technology will support.

Document for future reference, the final instructor model design requirements.

DEVELOP THE INSTRUCTOR MODEL OPERATING AND HUMAN FACTORS DESIGN

Develop a preliminary functional design and document it in sufficient detail so that diversely interested people, from training managers to working-level programmers, will understand how the instructor model is expected to work.

Within the system operating context, cover the seven significant subjects discussed in the previous section under the heading "Developing the Instructor Model Operating and Human Factor Design."

Try to resolve problems as they arise using the assistance of operational training experts where necessary. Do not hesitate to stop the design process if proposed solutions will cause the system design requirements to be eroded.

DEVELOP THE DESIGN REQUIREMENTS SPECIFICATION

Develop the instructor model design requirements specification using the organization shown in Figure B-4. The preliminary functional design document should be attached thereto.

Compose each specification item in detail using the abbreviation "TBD" (to be determined) when specific data is unavailable.

APPENDIX C

SIMULATION AND EVENT CONTROL MODEL DESIGN GUIDE

TABLE OF CONTENTS

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LIST OF TABLES

SIMULATION AND EVENT CONTROL MODEL DESIGN GUIDE

INTRODUCTION

The design guidelines for the simulation and event control model were developed under the assumption that the model will operate with an Automated Instructor Model (see Appendix B). However, this may not always be the case. Where departure from the guidelines herein are necessary, the document is appropriately annotated.

The design guide assumes that the user has a working knowledge of simulation in training systems and also has detailed knowledge of the training task to which simulation and event control modeling is to be applied.

The design guidelines for each section are preceded by related discussion and amplifying comments.

These design guidelines are intended to encompass the following design procedure as depicted in Figure C-1.

1. Define the type of information presentations which are required to meet the learning and instructional requirements set out in the curriculum.

2. Analyze the information presentation requirements for a potential system solution.

3. Develop a simulation and event control system design to fulfill the information presentation requirements.

4. Develop the simulation and event control model functional design requirements based on the information presentation analysis.

5. Assess the present simulation and event control model technology state-of-the-art and project the technology into the production timeframe of the training system.

6. Make the technical decision that the simulation and event control model requirements can be met within the required timeframe.

7. Develop the operating and human factors design of the simulation and event control model, including its interface with other elements and models which make up the training system.

8. Develop the requirement specification of the simulation and event control model so that it becomes an effective document for the designers, developers, and users of the training system.

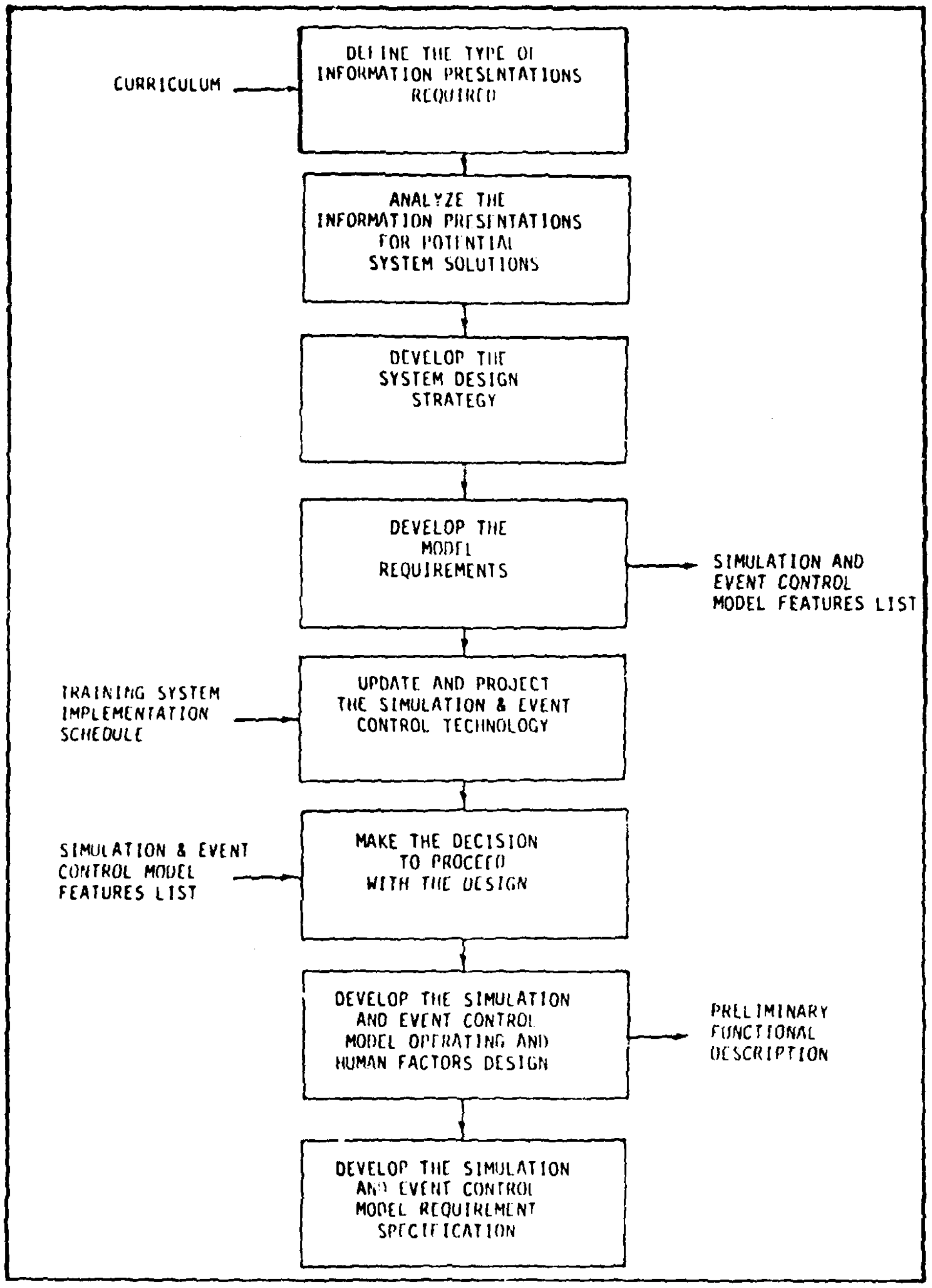

Figure C-1. Simulation and Event Control Model Design Guidelines

DEFINING THE INFORMATION PRESENTATION

In most training system endeavors, the operational training community can be expected to attempt to dictate the information to be presented in the simulation, and where possible, the fidelity required of it. However, in the end the instructional content of the curriculum and not subjective opinion, should dictate the information presentation. However, The training/systems analyst should heed the operational communities ideas but be prepared to market alternative approaches. Using a technically sophisticated example to illustrate the point, the operational people may think that they require a wrap-around point-source visual scene projection using a high resolution model board. However, the training/system analysts may decide that a wide angle back-projected TV screen using computer graphics will fulfill the curriculum requirements. A viable comment would be that the model board approach is an expensive and inflexiable approach compared to computer graphics (the advantages of CGI are an ongoing research issue). A further but simpler example is that the operational community may not have considered using speech generation to provide a verbal dialog in conjunction with a visual scene demonstration. In the view of the training/systems analysts this would eliminate the need for the trainee to read the instructions on a CRT terminal concurrently with viewing the demonstration. Note that in both examples, the presentation of information to the trainee would be arrived at by an analysis of training requirements as opposed to subjective opinion.

Therefore, the presentation of information really should not be decided upon until the training curriculum has been developed, at least to the level of key concepts and training objectives.

Once there is sufficient curriculum information available, the presentation of information can be arrived at by resolving the contents into visual and audible components. By definition the audible components are managed by the speech system (see Appendix A for Speech System Design Guidelines). The visual components should be further broken down into visual scene and information display components. The latter may involve CRT displays, numerical readouts and actual operational equipment. Remember that the trainee should not be expected to process too much information from diverse locations. In some circumstances it may be necessary to centralize or even condense the sources of information and consider eliminating everything but the visual scene during high visual learning activities.

Note that unless the presentation of information calls for a simple approach (like a CRT screen), the final solution normally demands a series of good technical arguments and a negotiated settlement.

ANALYZING THE INFORMATION REQUIREMENTS

The curriculum development is expected to provide details of the scenario requirements for a block of lessons or each lesson module. The scenario should contain the visual scene and/or information details to be

presented to the trainee. For example, if the curriculum calls for the scene to include an aircraft carrier, the information requirements should include the carrier type, speed through the water, aspects to the viewer, sea state, dynamics in six degrees of freedom, day or night, general visibility, color characteristics, etc.

By describing in detail each scene to be displayed, the overall information presentation can be defined. It is convenient to organize the requirements into the general categories of foreground and background information. The foreground information is primary information which will probably require realistic representation and realistic dynamic performance. The background information is all the other information which must be displayed. This would include other physical objects in the (such as support ships, land mass, etc.) alphanumeric data (such as instructions, speech recognition feedback) and environmental effects (such as reduced visibility, twilight, gunfire, etc.).

In the LSOTS, the perspective of the approaching aircraft to the landing signal officer is a most important factor. In the simulation of the landing aircraft the correct perspective is achieved by information resolution as seen by the LSO. Therefore, the training/systems analysts must decide on the visual resolution required to produce an acceptable presentation.

DEVELOPING THE SYSTEM DESIGN STRATEGY

The development is intended to delineate what simulation features are necessary to fulfill the information presentation requirements.

The strategy is developed by analyzing each visual scene and information display requirement to arrive at a top level system solution. A good way to express the system solution is in a block diagram. An example is shown in Figure C-2. Each interconnecting line between blocks, etc. should be identified with the information to flow along it. (See Table B-2, Appendix B for format ."

To assist in the development strategy, each information presentation requirement should be analyzed from the aspect of:

1. The general scenes to be presented, including environmental effects.

2. The alphanumeric and graphical data to be presented.

3. The interactions between the vehicle and driver.

4. The interactions between the vehicle/driver and other objects in the scene.

5. The impact which other models and systems will have on the presentation of information.

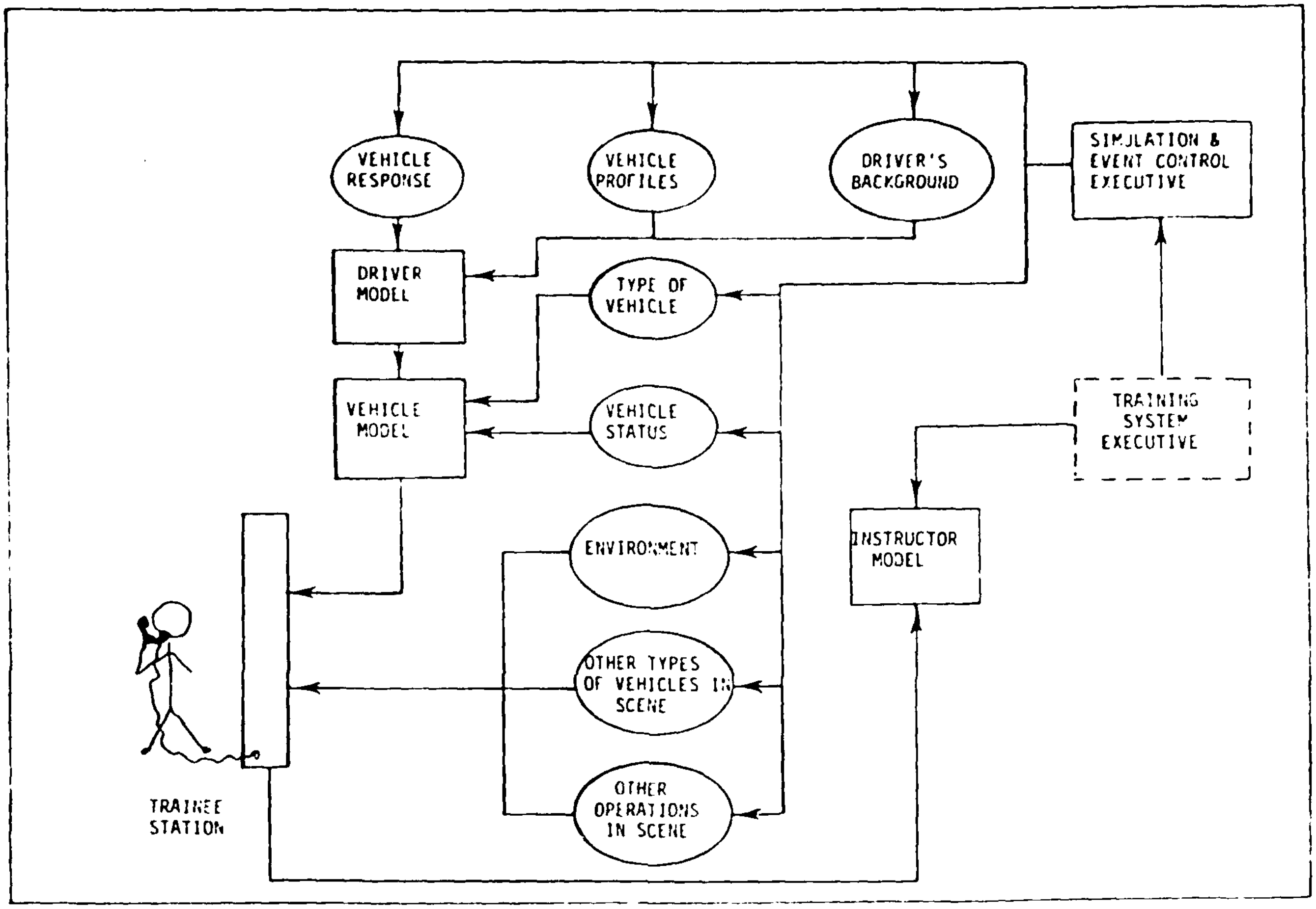

Figure C-2. Simulation Event Control Model Interactions

DEVELOPING THE MODEL REQUIREMENTS

The requirements for the simulation and event control must be specified for each training system application. Table C-1 lists the potential requirements which should be considered. For ease of use the table has been subdivided as follows:

Visual Scene Characteristics - the foreground, background, and environmental information presentations.

Information Display Characteristics - the display of alphanumeric or graphic data.

Scenario Generation and Housekeeping - how the information presented to the trainee (and/or the human instructor) is compiled and controlled.

Visual Scene Characteristics

Type of Scenes and Media - Prior to the availability of computer graphics for visual simulation, scaled models or films were the only techniques available. Computer generated scenes are not "real" and their training value is the matter of on going research by NAVTRAEQUIPCEN using the Visual Technology Research Simulator (VTRS). However, the availability of high resolution, large multiple-color displays suggests that computer graphics will prevail for most future training system applications.

Do not overlook that higher resolution displays are more demanding on software development and program storage and this must be traded off against the resolution requirements.

Type of Display - the use of a partially spherical dome is a well established technique for presenting a visual scene using a point source projection. The big advantage is that the scene remains "real" for a large area around the point source which will accommodate several people involved with training. However, this technique has the disadvantage of high initial costs.

Back projection of wide angle screens is an improving technology. However, large display angles require the use of edge-on-edge multiple displays set on a curve, the radius or focal point of which becomes critical for the user. Where high resolution perspective viewing is required, as used in the LSO reverse display training system, the trainer's use may be limited to one person (Hooks and McCauley, 1980).

In contrast, the training/systems analysts should consider whether the visual scene can be provided with several limited viewing areas as exemplified by the current use of four TV screens in the windows of several

TABLE C-I. SIMULATION AND EVENT CONTROL MODEL POTENTIAL REQUIREMENTS

VISUAL SCENE CHARACTERISTICS

Type of Scenes and Media

Scaled Model, computer generated, in combination, color, mono

Type of Display

Point source in a dome, back projection single/multiple projections, contoured/flat surfaces

Foreground Objects

Size, type, aspect, dynamics, resolution, lights

Background Objectives

Size, type, aspect, dynamics, resolution, lights

Environmental

Night, day, general visibility, lighting, sea state, cloud ceiling, special effects (like gunfire)

INFORMATION DISPLAY CHARACTERISTICS

Data to be Displayed

Narrative, tables, graphics, in combination

Type of Display

Superimposed on visual screen, CRT terminal, dedicated readout, printout, or in combination

Special Features

Light-pen touch selection, information display priorities

(Continued)

TABLE C-I
(Continued)

SCENARIO GENERATION AND HOUSEKEEPING

Scenario Generation

- Basic scenario
- Scenario detailing

Vehicle and Driver Model (when required)

Scenario Monitoring

- Real-time speech interaction monitoring (when required)
- Scenario control
- Visual scene status
- Queue control
- Vehicle/driver model status
- Scenario status monitor
- Recording and playback

heavy transport flight simulators (United Airlines 727 simulators at Denver, Colorado). The window support structure provides a natural division between the screens and the manipulative power of computer graphics accommodates the peripheral view. For alphanumeric and graphics display the technology is so well advanced that no further comment is required (see any commercial computer graphics terminal).

Foreground Objects - for convenience these are described as the objects which are central to training. Therefore, they should have high fidelity in terms of type, size, motion dynamics, perspective, resolution and other characteristics such as visible pertruberances and lights. These requirements should be defined accordingly.

Background Objects - for convenience, these are described as objects which support the forground objects. They can have lower fidelity than the foreground objects.

Environmental - these are variable effects which can be superimposed on any scene and cover night and day conditions, prevailing visibility, horizon definition, cloud ceiling, cloud types, sea state and special visual effects like gunfire.

Information Display Characteristics

Data to be Displayed - this covers all aphanumeric data and graphics. It is recommended that the analysts obtain sufficient information about the scenario so that the data to be displayed can eventually be developed on a scene-by-scene basis.

Type of Display - there are numerous ways of displaying data to the trainee. Dedicated CRTs are commonly used especially when data entry keyboards are included at the trainee's and/or human instructor's stations.

The arrangement of the trainee's station is considered to be part of the human factors design for the Instructor Model (see Appendix B). The use of several data displays must be done judiciously because they can distract the trainee's atttention from the primary viewing scene.

It is sometimes practical to superimpose limited amounts of data on the primary viewing screen. Such insertions should be unobtrusive and should be limited to such items as performance scores for the last training exercise or speech recognition feedback messages.

Scenario Generation and Housekeeping

Basic Scenario Generation - three basic requirements should be developed as follows:

1. Generation of the scenario for each training task to be taught in acccordance with the definitions provided by the curriculum controller.

2. Accommodation of environmental variables to the basic scenario as introduced by the trainee or human instructor to make the task easier or more difficult.

3. Continuous detailing of the task to ensure that no event which is planned to take place within the scenario conflicts with any other.

Vehicle and Driver Model - is a subsystem which provides the required range of vehicle and driver types. The type of vehicle and/or driver may be selected randomly or under control of the curriculum. It is customary to define the vehicle dynamics and the driver as two separate models.

Scenario Monitoring - three basic monitoring functions should be developed as follows:

1. Monitor the relationship among the scenario, the display contents, the vehicle/driver model status, and inputs from the speech recognition system (when used).

2. Provide event queue control so that no planned scenario event conflicts with any unplanned event provoked by the trainee or human instructor.

3. Control the recording and playback of all information, transmitted to and received from the trainee and human instructor during the course of a specific training session.

UPDATING AND PROJECTING SIMULATION AND EVENT CONTROL MODEL TECHNOLOGY

The purpose of this step in the development of the simulation and event control model is: 1) to gain information for application to a specific simulation and event control model based on the status of similar models; and 2) to project this information into the production time frame for the training system under consideration.

Descriptive documentation is not sufficient to provide the state-of-the-art technology update for the complicated systems discussed herein. Training/systems analysts also require direct experience with other training systems for an effective update to occur. The following technology features should be observed in other systems:

1. The type of visual scenes and alphanumeric (or other) data which is being used and the rationale for their selection.

2. The use of common displays to present different classes of information.

3. Physical limitations of the displays - such as acceptable for night but marginal for day.

4. Limitations of the displays - like insufficient resolution to define the shape of the vehicle at extended range.

5. In-service maintenance difficulties - like bias shifts of adjacent display elements.

The projection of simulation and event control model technology should consider three further points as follows:

1. The features which can be provided now but are not cost effective at the present time. The question is whether advancing technology will bring the cost down.

2. The features which are available now but are mediocre in performance. The question is whether advancing technology will enable the performance to be satisfactory.

3. Will the basic technologies being developed to display information, such as fiber optics, high resolution, TV, etc., revolutionize and surpass the current state-of-the-art?

Information display technology continues to advance so rapidly that it may be prudent to periodically submit a technical requirement paper to industry (world wide) to determine what is likely to be available for future training systems.

Each of the considerations for the updating and projection of technology for a specific simulation and event control model should be carefully documented for future reference.

DECIDING TO PROCEED WITH THE DESIGN

The decision process should be predicated on whether the projected technology for simulation and event control models will support the requirements for a specific application. Each documented requirement should be examined in this regard. Uncertainties about the technology suffiency should be related to their overall impact on the training system and discussed with the operational training community to determine alternative solutions.

The analyst's job becomes particularly difficult when confronted with a potential high technology solution which will provide effective training but which is difficult to "sell" to a conservative operational community. In these circumstances it is sensible to project both the new and old technologies in parallel, nominating a later decision date to select one technology depending on information gained in the interim.

The resulting final design requirements should be reviewed by the operational training community and should be documented for future reference (ee "Develop the Simulation and Event Control Model Specification.")

In general, time is on the side of the training/systems analysts when confronted with a decision on a technological uncertainty. However, in the case of simulation and event control models, and in particular the scene display element, the use of a new technology is a dubious choice unless the manufacturer is prepared to share the financial risk.

DEVELOPING THE SIMULATION AND EVENT CONTROL MODEL OPERATING AND HUMAN FACTORS DESIGN

Once the decision to proceed with the model design has been made the function operation and human factors design should be described in detail. The resulting document will become the preliminary functional description.

It is essential that the description be of sufficient depth and breadth to meet, on one hand, the requirements of training managers (who must plan how to use the system) and on the other hand, that it fulfills the detailed needs of the software programmers. In comparison to other training system models and subsystems, the detail required for the simulation and event control model is considered of utmost importance because it has the most "visibility" to the user.

Six significant subjects should be covered in the description. These are:

1. The content of the visual scene for each change in foreground/background objects, and environmental effects. Where practical, drawings should be used in lieu of words. Special attention is required to describe the dynamics of each object and/or effect and their interactions.

2. The content of the data information presentations on a page-by-page basis. Where fixed formats are anticipated, examples of content should be given. Particular attention should be paid to page sequence after selection thru the use of keyboard entry, touch controls, or light pens.

3. The vehicle's dynamic performance and its relationship to the driver model. The equations of motion (in six degrees of freedom) for each type of vehicle model to be displayed is part of this requirement.

4. The rules which will be used to generate the scenario from the lesson content provided by the Instructor Model. This should include the rules for modification of the scenario by the human instructor trainee.

5. The rules of order for the scenario monitor.

6. The rules for recording, freezing and redisplaying (playback) of visual scene and information data for a specific training session.

It is recommended that these six subjects be addressed in the context of working through typical and atypical training scenarios from the time the trainee (and instructor) sign-on to the system to the time they sign-off.

The functional design is an exacting process which can be expected to reveal new instructional, display, and human factors problems. No problem should be exempted due to difficulty. Each must be resolved in a timely manner. The use of operational training experts normally is essential for a functional development envisaged by this guideline.

DEVELOPING THE SIMULATION AND EVENT CONTROL MODEL REQUIREMENT SPECIFICATION

This specification is the culmination of the preliminary design process and should be predicated on the design requirements for the model and the preliminary functional description.

An organization for the specification is shown in Figure C-3. The preliminary functional description should be added as an attachment thereto. The specification should not be written for a general simulation and event control model. It should specifically address every known aspect of the model under consideration.

Generic treatment of specifications is resorted to when the writers do not fully understand the subject matter and/or recognize when details are required. This practice can cause problems when the specification becomes part of a contract. For details which are unavailable at the time the specification is written, it is prudent to use the notation "TBD" (to be determined) and then to make the "determinations" part of the contract.

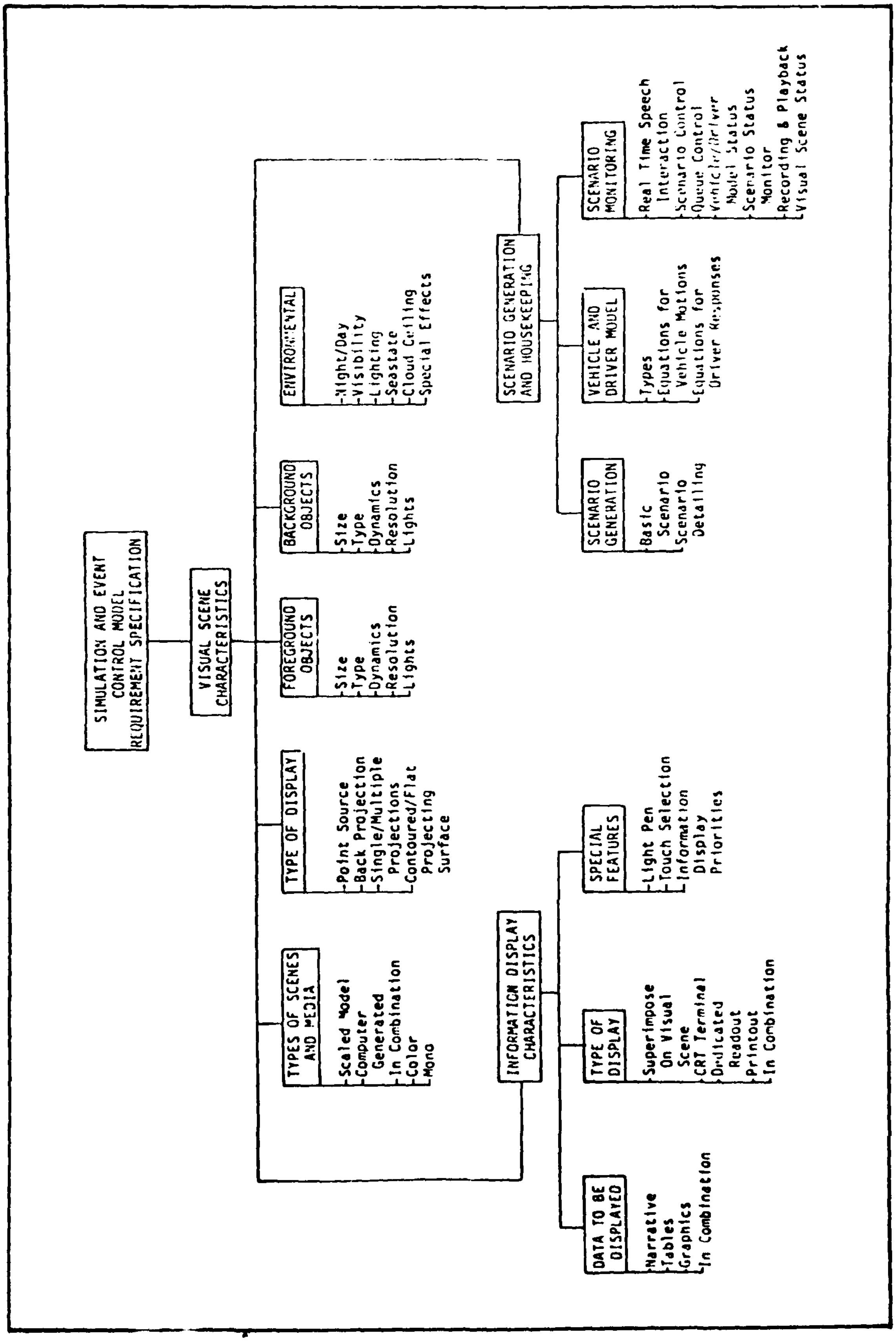

Figure C-3. Simulation and Event Control Model Requirement Specification Organization

DESIGN GUIDELINES

GENERAL APPROACH

Figure C-1 presents a design procedure intended to provide guidance to training/systems analyst and system engineers (the training system design team) on the implementation of an automated simulation and event control model to support training.

ANALYZE THE INFORMATION REQUIREMENTS

Break each visual scene into three components (foreground objects, background objects, and effects), ensuring there is a good understanding of their characteristics and interactions.

Define the set of common objects, unique objects and effects which have to be simulated.

Define the dynamics and resolutions required for the foreground and background objects.

DEFINE THE INFORMATION PRESENTATION

Allow sufficient time for the key training concepts and training objects to be developed as part of the curriculum design before proceeding with the information presentation definition.

Resolve the curriculum information into visual scene and information display. Allocate the information display to CRTs, dedicated readouts and operational equipment.

Guard against the display of too much information to the trainee at any instant.

Do not allow preconceived notions of how the visual scene and data information should be presented to the trainee to prempt the orderly analysis and progress towards the best solution.

DEVELOP THE SYSTEM DESIGN STRATEGY

Develop a top level system design that will provide the simulation and presentation of information to fulfill scenario needs.

DESIGN GUIDELINES

Develop a series of block diagrams to describe the major elements of the simulation and event control model, tabulating the information which must flow internally between the blocks and interfacing systems.

Where interfacing systems, e.g., an existing visual display, ensure that the required information flow to and from the simulation and event control model is available and in a manageable format.

DEVELOP THE MODEL REQUIREMENTS

Develop a set of specific design requirements based on the potential requirements listed in Table C-1.

Document each requirement using a format so that it may be evaluated in terms of available technology.

UPDATE AND PROJECT SIMULATION AND EVENT CONTROL MODEL TECHNOLOGY

Relate each specific model requirement to the technology available to fulfill it. Take into consideration the training system production time frame. Weight your findings accordingly.

Witness the operacion of recently developed training systems to gain first hand of their simulation and event control performance. Firmly establish the expectations of other simulation efforts which are in the design and development stage and weight your findings accordingly.

Evaluate other advancing information display technologies which have the potential of fulfilling the simulation and event control model under consideration. Look into their success in other applications and draw conclusions as to their viability for the specific training system application being considered.

DECIDE TO PROCEED WITH THE DESIGN

Make a decision to proceed (or not) on the outcome of the analysis of matching the requirements with the available technology.

When the answer is not clear, the operational training community can help to evaluate alternative training strategies that will fit within the technology expectations of the production time frame.

DESIGN GUIDES

Reiterate the design requirements until there is a feasible match between operational training needs sand what the technology will support.

Do not hesitate to consider an alternative candidate for the visual scene display if the newer technology looks promising. Set a date to make a final decision on which technology to use.

Document for future reference, the simulation and event control model design requirements.

DEVELOP THE OPERATING AND HUMAN FACTORS DESIGN

Develop a preliminary functional design and document it in sufficient detail so that diversely interested people from training managers to working level programmers will understand how the Simulation and Event Control Model is expected to work.

Within the system operating context, cover the six significant subjects discussed in the previous section on operating and human factors design.

Try to resolve problems as they arise using the assistance of operational training experts where necessary. Do not hesitate to stop the design process if the proposed solutions will cause the system design requirements to be eroded.

DEVELOP THE DESIGN REQUIREMENTS SPECIFICATIONS

Develop the Simulation and Event Control Model requirements specification using the organization shown in Figure C-2. The preliminary functional design document should be attached thereto.

Compose each specification item in detail using the apprevation "TBD" (to be determined) when specific data is unavailable.

APPENDIX D

AUTOMATED TRAINING SYSTEM INTEGRATION DESIGN GUIDE

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LIST OF TABLES

AUTOMATED TRAINING SYSTEM INTEGRATION DESIGN GUIDE

INTRODUCTION

The design guidelines for automated training system integration are oriented toward the relationship among an automated speech system, instructor model, and simulation and event control model. These guidelines also address the design considerations when only two of the foregoing training system elements are used, or in some instances, when only one system element is used with an existing simulator or trainer.

The design guide assumes that the user has a working knowledge of speech systems, instructor models, and simulation and event control model designs and the interrelationships between them.

The design guidelines for each section are preceded by related discussion and amplifying comments.

System integration is a broad subject. For this design guide the following subjects are:

1. Automated training system integration design - system partitioning, and interfaces with existing simulators or trainers.

2. Examples of training system integration design - existing and proposed.

3. Concepts for the design of training system executive controls .

SYSTEM INTEGRATION DESIGN

The present partitioning of systems and models used in automated training system design largely has occurred along the same lines as the technology development (speech, instructional, and information display).

Figure D-1 shows the global system concept of using three "satellite" systems working under the direction of a training system executive control. Each of the "satellites" is a self contained system with its own executive control.

Speech interactive training systems like PARTS and ACE have been designed to provide the functions of the three satellites (speech, instruction, and information display) without a recognizable training system executive control system. In these designs, multiple computers and peripherals have been used to mechanize the system. This technique is not conducive to functional change. More importantly, it is difficult to use this system integration experience to design systems using different combinations of the satellites.

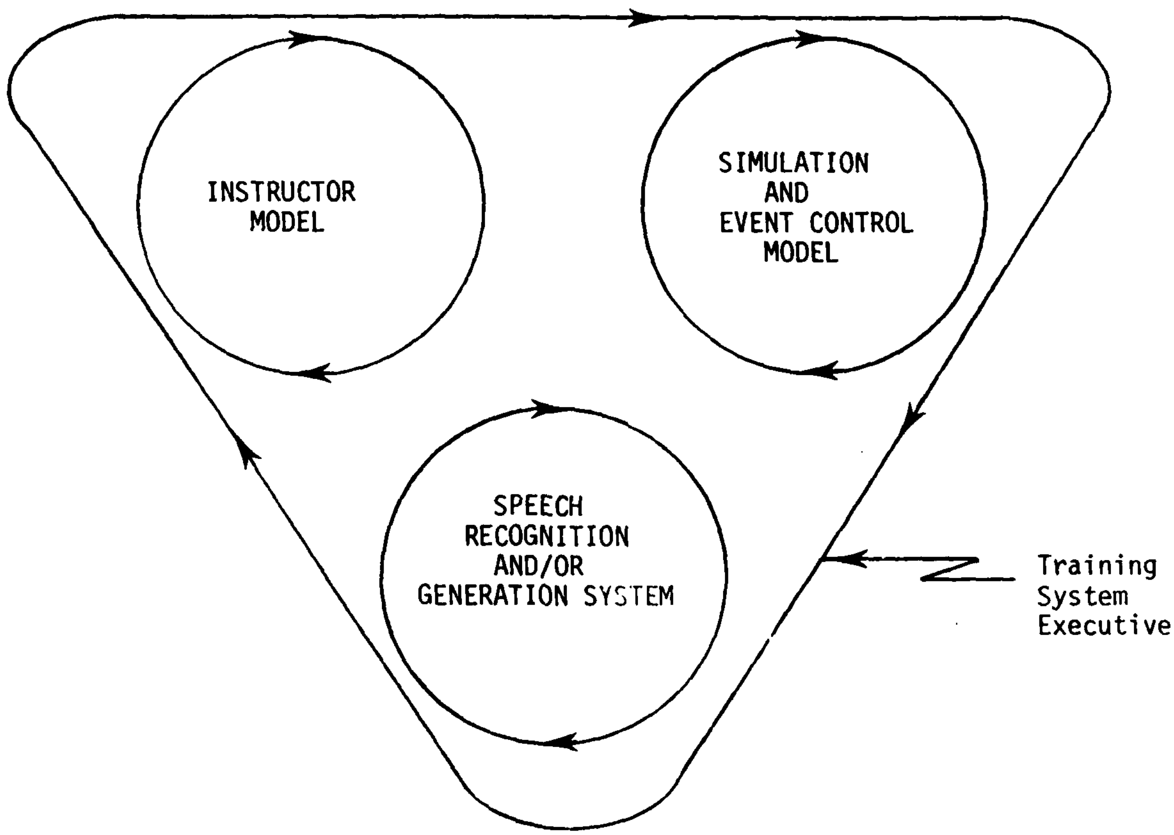

Figure D-1. Self-Contained, Voice Interactive Training System: Subsystem Relationships and Executive Control

Different combinations of the satellite system (see Figure D-2) can be considered as follows:

1. Instructor Model with a Speech System working with an existing simulator.

2. Simulation and Event Control Model with a speech system working with an existing instructor's console and display system.

3. Instructor model working with an existing simulator.

4. Simulation and event control model working with an existing instructor console and display system.

5. Instructor model in a computer assisted instruction application.

Examples of integration of the various training system elements are given in this document. The training system design team is cautioned about the considerations which must be given to the integration of the instructor model, simulation event control model, and speech system with an existing simulator or piece of training equipment. Details of the functional and electronic characteristics of the proposed interface with the existing system should be carefully examined before the feasibility of system integration can be determined.

EXAMPLES OF TRAINING SYSTEM INTEGRATION

The nature of a training system functional integration is dependent on the tasks to be learned. There are innumerable variations that can be discussed. However, there are three primary system categories which are depicted in Figure D-3 and summarized as follows:

Speech Procedures Driven Systems - in which the verbal communication between the automated system and the trainee is the focal point of training. Without a primary need to develop speech skills, the training system would not exist. Existing examples of this type of system are PARTS, ACE, and LSOTS.

Task Procedure Driven Systems - in which the training system primarily is used to develop these skills and may or may not include speech interaction. An example of this type of system is the F-14A Instructor Support System (F-14 ISS).

Control Strategy Driven System - in which the training system is used to develop trainee information selection strategies based on discrete inputs by the trainee. The inputs could be by keyboard or voice. An example of this type of system is a troubleshooting system for maintenance training.

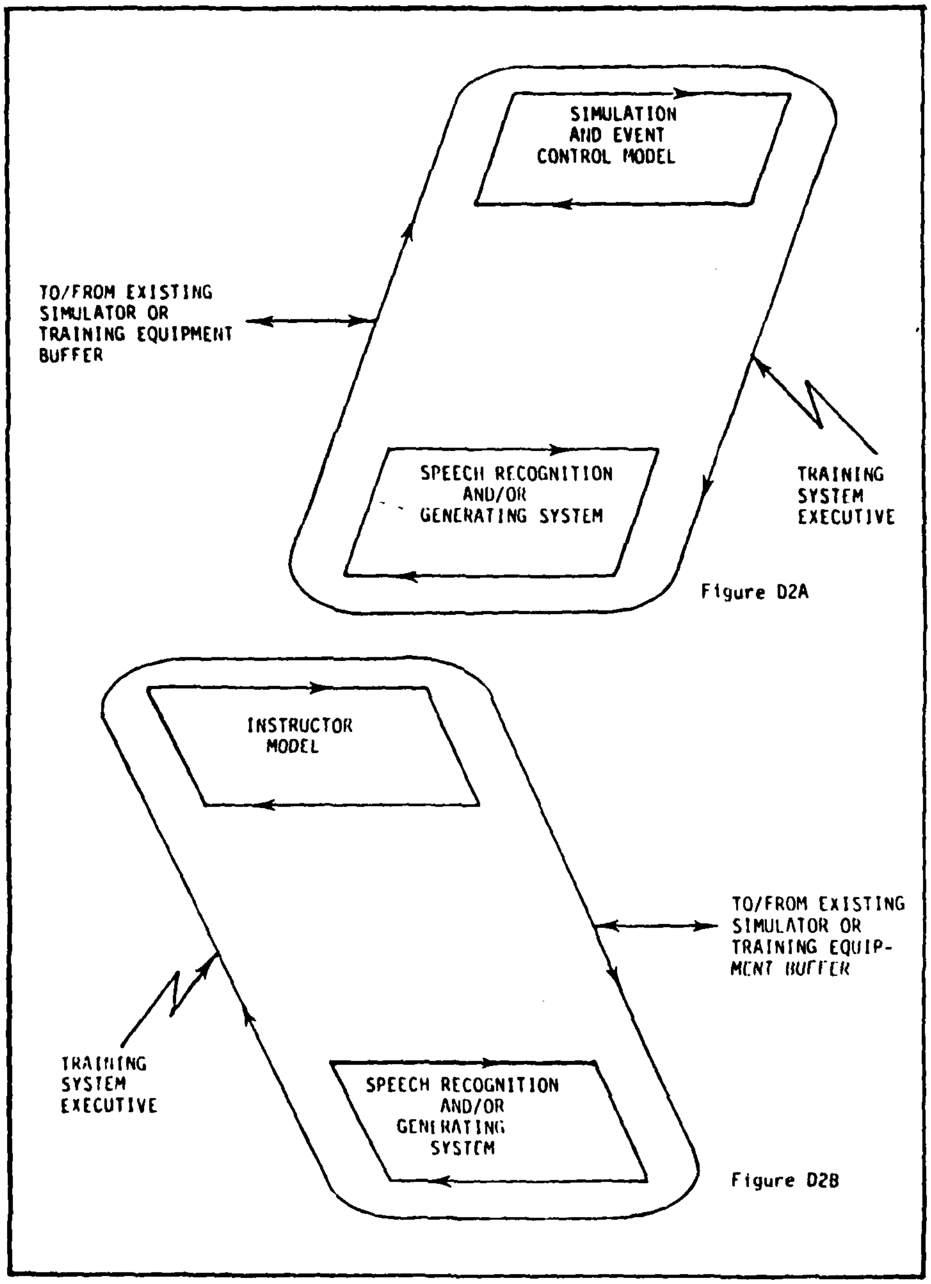

Figure D-2. Alternative Training System Strategies

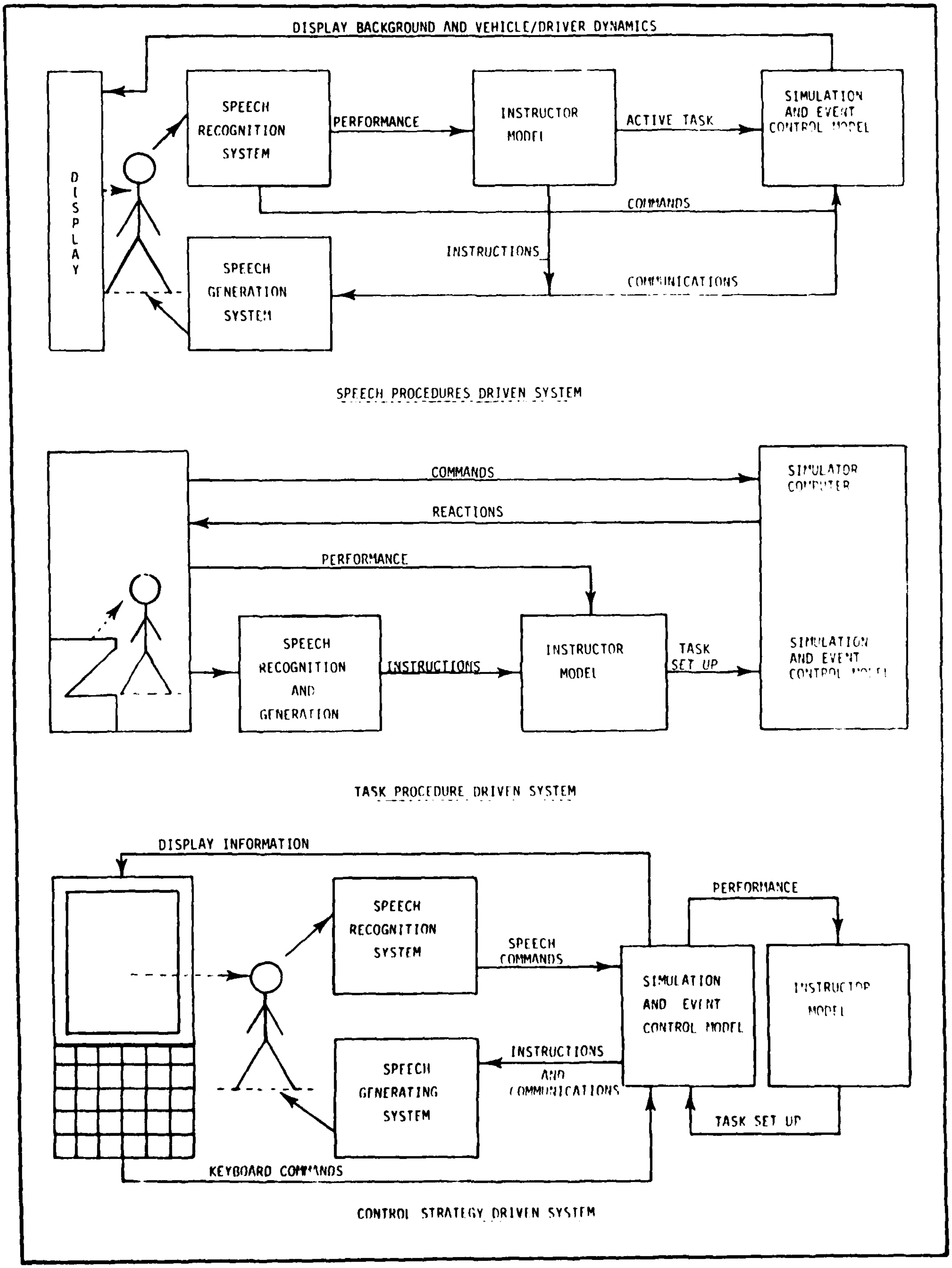

Figure D-3. Primary System Categories

Speech Procedures Systems

These v^ctems are critically interactive because the training system control loop is closed through the trainee. Except for the instruction feature, the training system must react in a real time situation. For each trainee speech utterance, the training system should provide feedback. The allowable time for each training exercises to take place (30 second exercises at 1 1/2 minute intervals for LSOTS), imposes a heavy burden on the system designers to integrate the system element and models so that the commensurate information flow is assured. In some instances the system integration design will impact the operation of the system elements and models which it supports. For example, in the LSOTS, the scenario sequence details for each training exercise, could be compiled in the instructor model. However, due to anticipated timing constraints of moving the data to the simulation event control model, the training/systems analyst selected to store the scenario details as part of the latter model.

Task Procedures Systems

These systems are interactive at the task execution level which means that the trainee and the vehicle/dynamics constitute the control loop. The instructor model and speech recognition and generation system are convenient additions to the training system to eliminate the need for a human instructor. The feedback provided to the trainee is the response of the vehicle. In this type of system integration, the vehicle dynamics and the trainee reaction become the critical factors to be considered for data transfer design.

Control Strategy Systems

These systems are interactive at the trainee level but differ from speech procedure driven systems because the trainee/system interaction is designed as an iterative process to arrive at a satisfactory conclusion. These systems can be keyboard or voice driven. After an entry is made by the trainee, there is a permissible finite time for the training system to react. Each training system reaction provides feedback to the trainee. The reaction may be a discrete event like moving a symbol on a display screen, or a interrogative response which asks the trainee for more data or to make a choice. The importance here is that an ongoing interactive training format requires the instructor model design to have a large hierarchical structure. However, the data flow requirements normally are not taxing.

CONCEPTS FOR THE TRAINING SYSTEM EXECUTIVE CONTROL DESIGN

The primary purpose of the training system executive (TSE) is to maintain a functional and rational interrelationship between the various elements of the training system at all times as depicted in Figure D-4. It is the "executor."

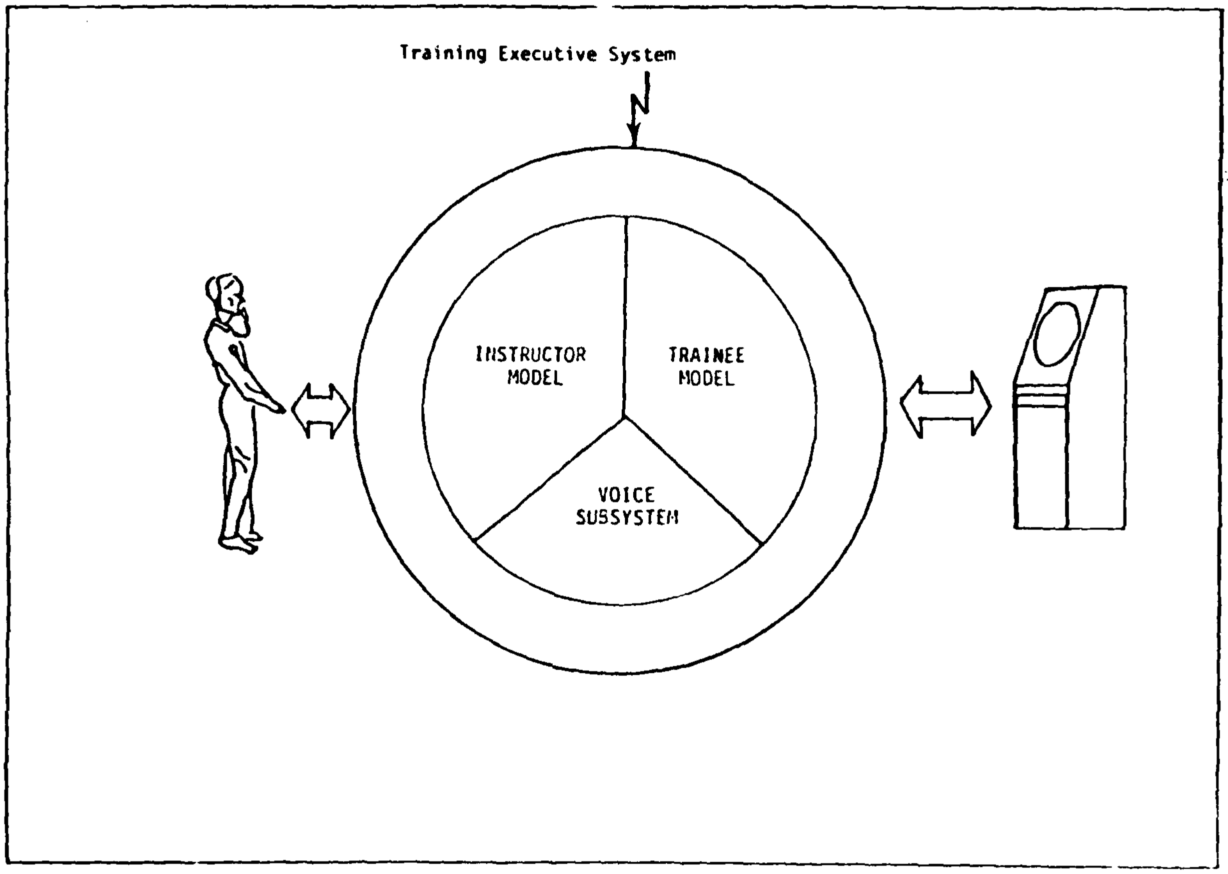

Figure D-4. The Importance of the Training System Executive

For a self contained training system as depicted in Figure D-1 TSE is envisioned to provide inter model/subsystem control for:

- System operating modes
- Curriculum control
- Active task selection
- Trainee and human instructor inputs and outputs
- Simulated environmental condition
- Vehicle/driver model or equivalent body dynamics
- Performance measurement and evaluation
- Diagnosis of the trainee performance
- Storage of performance data of the active task
- Playback of the active task
- Filing of trainee instructor and class records
- Speech data collection
- Speech recognition
- Speech generation

The design concept for the TSE is that each system element or model of a training system has its own internal executive control (see Figure D-1 and D-2). It is then the responsibility of the training system executive to manage the information flow between the satellite control systems when "flagged" to do so. This concept supports the increasing use of multiple microprocessors for distributed processing of large computing tasks. However, when a mainframe computer and a group of interfacing peripheral equipment must be used, the TSE is conceived as interacting directly with the computer's resident operating program. Additionally, the TSE is conceived as providing the interface with existing simulators or training equipment using microprocessors for information buffering.

Points to be considered in the design of a TSE for a specific training system application are shown in Table D-1. The design should be predicated on loose coupling between systems. This enables the processing of raw information, the flow of which is controlled by the TSE, to become the responsibility of the system element or model receiving it. This concept allows each system or model to control processing in its own internal time frame, and in the most efficient manner.

DEFINING THE INFORMATION FLOW BETWEEN SYSTEM ELEMENTS

The following steps should be used in defining the degree of integration of the training system design.

1. Define every computing function to be used in the training system (see Figure D-5 as an example). Identify which functions have critical timing requirements, establish whether the data resulting from the computation remains internal to the system element, or is outputted to another system element.

TABLE D-1. POINTS TO BE CONSIDERED WHEN DESIGNING A TRAINING SYSTEM EXECUTIVE

TSE Tasks	- Definition, analysis of content, integration with other models and systems
Scheduling	- Realtime, near realtime, offline, hard copy, time sharing for multiple trainee participation
Monitoring	- Exercise sequencing, unnatural circumstances, self test, diagnostics
Rules of Operation	- General flow, special cases, design conventions
Priorities	- Message cueing, message bypass hierarchies
System Security	- Sign on/off, beating the system, record protection

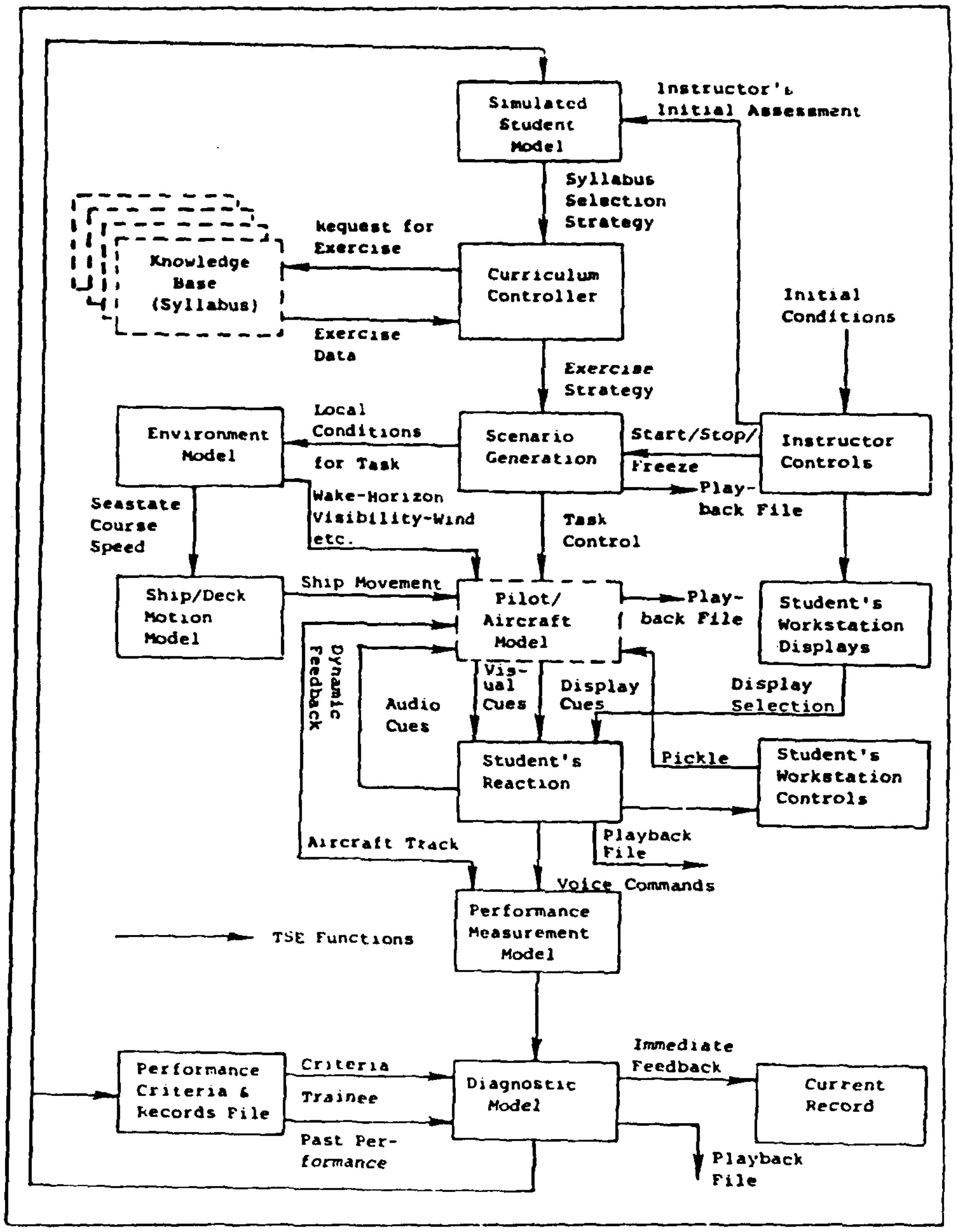

Figure D-5. Data Flow Between System Elements for a Candidate LSOTS

2. Define the internal computing functions to be controlled by each system or model internal executive control, including its timing priority and data format.

3. Define the "external to" or system input/output data to be managed by the TSE, including its timing priority and data format. Specify priority interrupts as necessary.

4. Develop a document which describes how each system element is to be integrated with other systems and models. Include the data processing requirements internal to each element and data flow between elements.

Each computing function should be described using a standard format an example of which is shown in Figure D-6. Where the system size is not overwhelming the computational flow can be developed by using a modified PERT chart approach. (See Figure D-7.)

Experience with PARTS and ACE emphasizes the need to establish realistic timing priorities so that the trainee operates in a environment conducive to efficient training. It is very necessary that the training system visibly or audibly react to a trainee input within 1 second. It is unreasonable and frustrating if the trainee has to wait 10 seconds because less visible software programs are given priority. These days, prolonged waiting is probably the outcome of inadequate software processing priority design, not inadequate computer capability. It is essential that the training systems analysts establish the overall training system priorities early in the design process. These priorities should be based on optimizing the trainee's interaction with the system. An organizing order for timing priorities is as follows:

<u>Priority Interrupts</u> - All other computing functions cease pending completion of the priority interrupt computing.

<u>Interrupts</u> - Allows all other computing functions to continue to a convenient point (no longer than 10 milliseconds) and then to cease pending completion of the interrupt processing.

<u>Foreground Computation</u> - Involves a group of programs, the execution of which is essential for the conduct of the training task. For example, performance measurement, visual scene updating, etc. The execution of the foreground computations has a priority structure unto itself so that essential computing is done ahead of computations of lesser importance. Foreground computation is surpassed by the priority interrupt and interrupt programs.

<u>Background Computation</u> - Involves a group of programs the execution of which is nonessential for the conduct of the training task at hand. For example, adaptive revision of the trainee model, filing the execution of

PROCEDURES MONITOR

FUNCTION: This process will determine the correctness of various cockpit procedures based on a predetermined procedural template. Pilot actions, changes in instrument readings, and touch pad inputs will provide the input from which procedural steps are derived. Inputs will be described as discrete events and will be detected by the central event detector.

This process will be created by the Instructor Control process at the start of an exercise and will be terminated at the completion of the exercise. It will not be involved with mission debriefing or replay, only mission execution.

Events will be checked for legality within the current procedural context and for correct order of occurrence. One or more activities may be associated with the occurrence of a single event. Activities may be made contingent upon the occurrence or non-occurrence of previous events. This mechanism will allow the definition of procedural completeness to be dynamically modifiable dependent on prior procedural steps. This contingency logic also means that a pilot's procedures score will be based on a flexible template which can adjust for changes in aircraft configuration or environment rather than on a fixed procedural definition.

The Procedures Monitor will support a separate monitor task for each active task module. These tasks will run asynchronously, each task receiving event occurrence IPC messages. A single body of reentrant code will be shared by all monitor tasks in performing monitoring logic but a separate data structure representing the procedural template will be maintained by each monitor task in an unshared data area.

PRIORITY: 6

TYPE: Preemptible

FREQUENCY: Less than 1/sec. asynchronous

STORAGE: 12 K shared
9 K dedicated

Figure D-6. Typical Computing Function Description

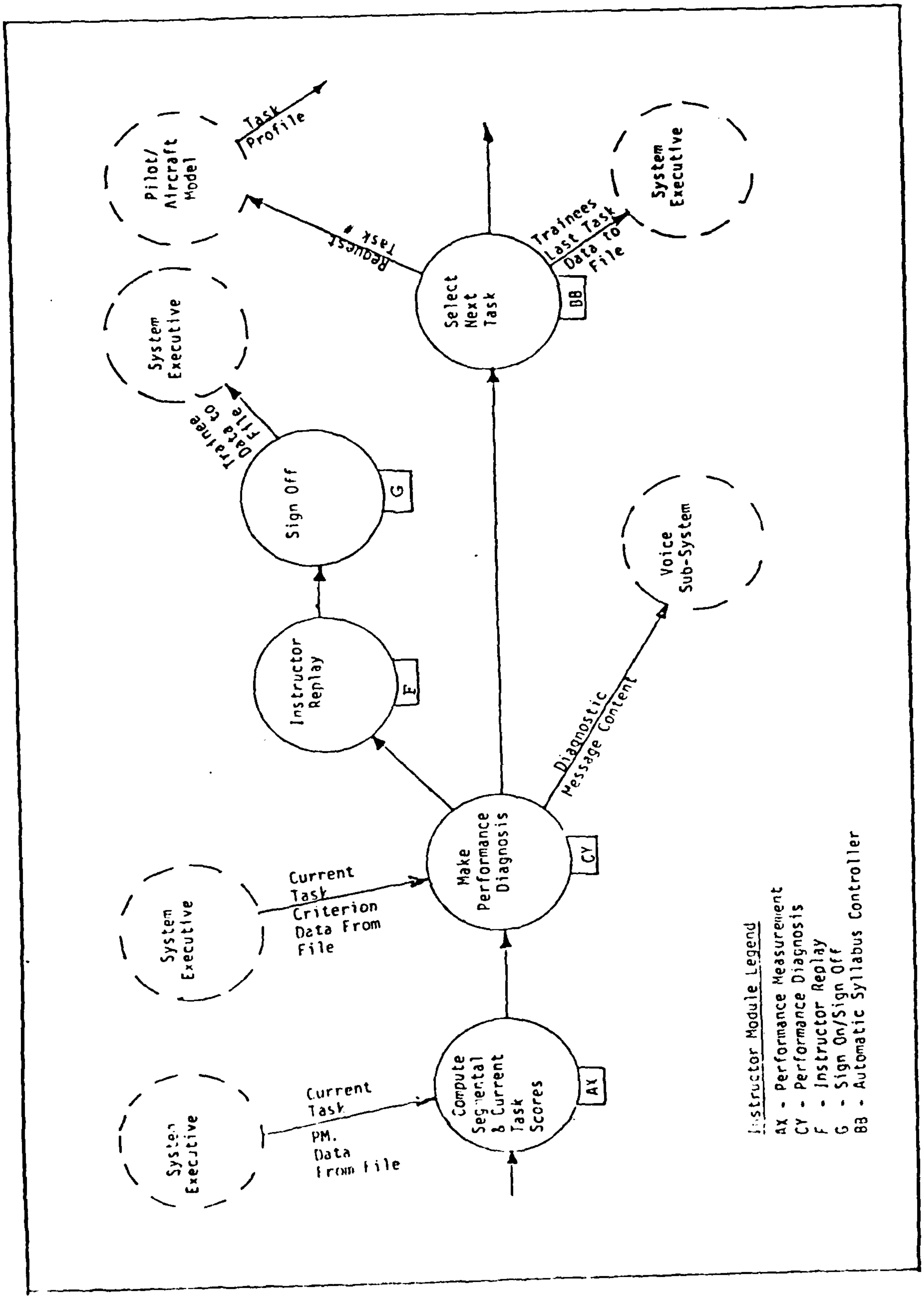

Figure D-7. Example of Part of an Event Sequence Map

the background computation has a priority structure unto itself so that the more important computation is done ahead of computations of lesser importance.

DEVELOPING A FUNCTIONAL SOFTWARE REQUIREMENT SPECIFICATION

Table D-2 should be used to develop the software functional requirement specification. Note that when the information flow between system elements is properly defined (see defining the information flow between system elements) the outcome will provide the greater majority of the information.

Two later additions to the specification should be provided for: 1) the description of the interface between the TSE and the vendor-supplied standard operating program and; 2) the description of the interface between the simulation/event control executive control program and the vendor-supplied visual scene display servicing program. Neither program can be completely specified until systemware is selected. However, an early and well defined description of the interface as seeen by the TSE and the simulation/event control executive is a prerequisite to a satisfactory design.

TABLE D-2. TRAINING SYSTEM EXECUTIVE ANALYSIS TASKS

Requirements	- Operations With Other Subsystems - Operating Tasks - Sequencing - Security
Organization	- Partitioning - Scheduling - Tasks Allocated to Software - Tasks Allocated to Hardware - Tasks Allocated to Courseware - Time Sharing - Interfaces With Unique User Equipments
Rules of Operation	- General Flow of Information - Special Information Flows - Message Cueing and Bypass - Housekeeping/Self Test - Records

DESIGN GUIDELINES

DEFINE THE SYSTEM INTEGRATION REQUIREMENTS AT A GLOBAL LEVEL

Partition the system functions to minimize the information flow between major parts of the training system.

Ensure that when a new training system is to be integrated with an existing piece of training equipment the resultant interface design is manageable.

Examine any critical timing constraints imposed by the training scenarios to ensure that data flow between system elements is manageable.

DEFINE THE INFORMATION FLOW BETWEEN SYSTEM ELEMENTS

Define every computing function to be conducted in the training system.

Identify which system element or model is responsible for the computation.

Describe whether the computation has input/output data requirements - if so, describe the data format and the timing priorities to be established by the TSE.

Document the foregoing information as part of the functional software description.

DEVELOP A FUNCTIONAL SOFTWARE REQUIREMENT SPECIFICATION

Develop a formal specification which describes the overall software requirement for the training system.

Document the computing functions to be conducted in each system element or model and the data interchange between them. Computational, input/output timing, and data storage (permanent and temporary) requirements should be established for each computation.

Identify common operating programs which are required to be resident in the computer system to support the training system software (files, software update, self test, diagnostic, etc.).

APPENDIX E

DESIGN AND DEVELOPMENT EVALUATION GUIDELINES

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INTRODUCTION

The design and development evaluation document is a compendium to the design guides presented in Appendices A through D. It came into being because the authors strongly believe that design evaluation followed by developmental test, evaluation and revision are the cornerstones of successful system development. A proposed OPNAV Instruction (Cordell, Nutter, and Heidt, 1979) is recommended as the guiding document for the test and evaluation process applied to training systems.

The present document assumes that the user has a working knowledge of interactive training system design principles, a detailed knowledge of the specific training task, and is familiar with the training system design team's endeavors. The content is divided into two sections, addressing system design and system development respectively. We recognize that this distinction may not be clear for all systems.

Evaluating the design of a large complex training system at any stage in the design and development process is a difficult problem which must be addressed. Training systems which are designed, developed and built under a judicious, well organized design evaluation policy will be more successful in the operational environment.

Design evaluation normally is an ongoing practice of good designers, whatever their discipline. Design evaluation should be practiced on a day-to-day basis within the design team. It should also be expanded to include scheduled design reviews by other people with related expertise, at which time the design team justifies the design to their peers. Critical matters can then be carried over from one review to the next.

PRINCIPLES OF ONGOING DESIGN EVALUATION

Many projects suffer because there is no design evaluation structure, insufficient design review, and/or the reviews are not conducted in a diligent manner. Consequently, problems that are not solved quickly become neglected under the pressures of maintaining a design schedule. The revelation of the problem invariably occurs during system test. Design evaluation is an iterative process that has its genesis within the design team. It includes higher level design reviews conducted by peers to detect errors in the lower order processes. However, the project manager must assure that the design evaluation requirement does not consume project resources to the detriment of the design process.

As the design proceeds, the evaluation process leads to higher level reviews which normally are conducted by the users, sponsors and project management. These higher level reviews should be based on a hierarchical structured review process that has been established in advance. It is the responsibility of the reviewers to assure that the lower processes have been adequately designed, and to help resolve any outstanding problems.

DESIGN EVALUATION GUIDELINES

1. A design evaluation checklist should be established at the beginning of the project and used throughout the design phase. An example of organization for the evaluation is shown in Figure E-1. It requires a large initial effort by the project manager to document in detail the design process from the initial design phase through the end of system test. Obviously, the organization is subject to change as the system design and development unfolds.

2. Each member of the design team should bear the responsibility of reviewing his/her own work and the work of other collegues on a daily basis.

3. Each week the design team should evaluate the current design tasks in a group meeting. The person responsible for the task must justify his/her design decisions to all concerned.

4. A peer design review team should evaluate groups of completed tasks and reiterate perceived problems through the design team. The peer design review team should sign off on each design task documenting their remarks where necessary for the information of the project manager.

5. The project manager should organize and conduct higher level design reviews with his/her management, the users and the sponsors of the training system. The design evaluation of each completed task should be documented, noting problems which were encountered, their solutions, and residual effects. Efficient documentation is required to avoid undue time loss.

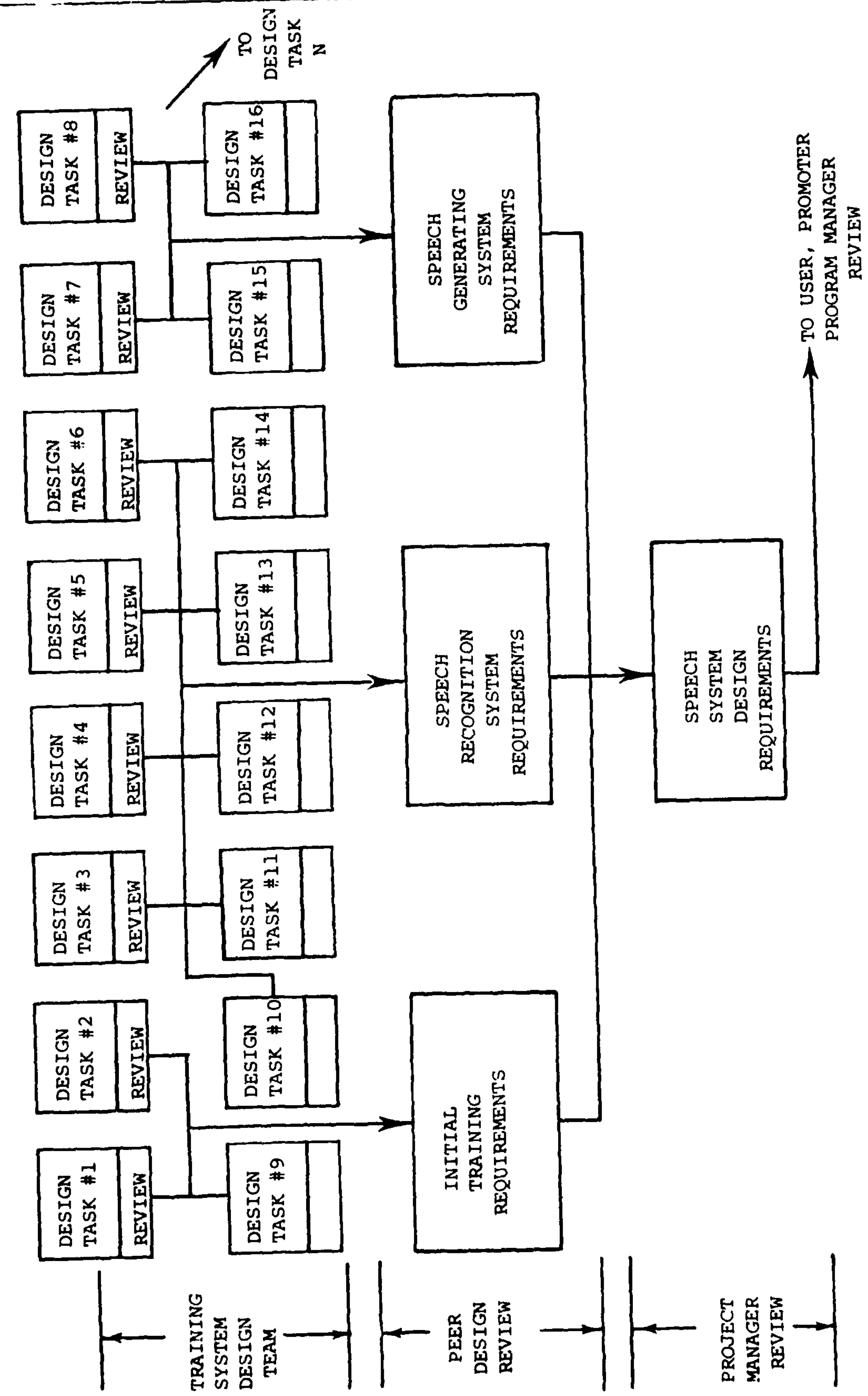

Figure E-1. Hierarchical Approach to Design Evaluation

DEVELOPMENT EVALUATION GUIDELINES

INTRODUCTION

Developmental test and evaluation (DTE) should occur throughout the development cycle of an AST training system (see Figure 3, presented earlier in Section V). As each critical configuration item is developed, such as the automated performance measurement software, it should be tested and evaluated. Revisions should be made according to the results. This cycle of test evaluate, and revise (TEAR) should occur regularly during the development of the system. It should occur not only at the level of critical configuration items, but also during integration of the items into the subsystems, such as instructor model and simulation/event control.

Most importantly, the TEAR cycle must be executed at the final stage, after the subsystems are integrated into the prototype training system. The evaluation criteria for the TEAR process will change as it is applied at different stages of system development. The TEAR process at the final integration stage will involve top-level criteria such as, what is the training effectiveness of the total system. A structure for the various levels of evaluation criteria should be generated before the development is begun.

Recommendations for allocation of the responsibility for TEAR is beyond the scope of this report. As an informal process, TEAR may occur on a regular (daily or weekly) basis by the contractor's training system development team. The procedures for more formal DTE are promulgated in a proposed OPNAV Instruction (Cordell, Nutter and Heidt, 1979). A Device Test and Evaluation Master Plan (DTEMP), as decribed in the proposed OPNAV Instruction, is in part, a vehicle for establishing check points for when more formal DTE is conducted by an independent evaluation team. The DTE followed by revision, is necessary to promote the ultimate achievement of program objectives, i.e., an effective and efficient training system that enjoys good user acceptance.

The TEAR process should examine whether the functional design requirements have been satisfied. Whenever possible, the TEAR should assess the performance of each component quantitatively. These measures must be evaluated against criteria derived on the basis of conformity with the functional design requirements. For example, a functional design requirement (or key functional characteristic) might state that the speech recognition system should be capable of operating under ambient noise conditions equivalent to those found at the intended site of the training system. The TEAR process would require, first, that the noise at that site be measured under appropriate conditions. Second, various noise-cancelling microphones might be used with the recognition system to determine their effect on recognition accuracy in the noisy environment. This TEAR step would produce confirmation that a particular recognizer and microphone were suitable. Furthermore, if information about mic placement or volume

adjustment were obtained in the TEAR process, it would be forwarded to the courseware developer to become part of the procedural instruction for the trainee.

In summary, the repeated TEAR process, whether conducted informally by the contractor, or formally, as a DTE functional configuration audit, must determine compliance with the functional design requirements. This determination is made, whenever possible, by devising quantitative tests and generating explicit evaluation criteria.

Examples of some of the issues that might be relevant for TEAR in a speech subsystem are given in Table E-1. This list is not exhaustive, but serves merely to illustrate the level of simple but important questions that should be confronted during, rather than after, system development.

The final stages of system development require the TEAR to be directed toward the most global evaluation criteria. Effective training should be the ultimate test of a training system. Short of performing a full training effectiveness evaluation, the TEAR process can be valuable by addressing issues such as:

curriculum content
tutorial techniques
instructional features (freeze, slow-motion, playback, etc.)
performance measurement
pacing of entire training course
servicing the trainee's perceived instructional needs, such as

- request for instructor
- request review
- request break
- request greater difficulty

servicing the instructors needs, such as

- request current trainee status
- request trainee's records
- request trainee's class standing
- request diagnosis of strength/weaknesses

A group of SMEs from the operational training community should be involved in the TEAR process at the final integration stage of training system development. Their opinion represents a valuable indicator of training effectivenesss and user acceptance. Their comments and critique should be weighted heavily in the subsequent (and critical) revision.

TABLE E-1. EXAMPLE ISSUES FOR DEVELOPMENTAL TEST EVALUATION AND REVISION (TEAR) OF AN AUTOMATED SPEECH SUBSYSTEM

Vocabulary Analysis and Speech Data Collection (SDC)

Does it comply with the operational task?
(Do speech recognition constraints compromise the use of operational vocabulary?)

How much time is required for SDC?
(assessing a speaker-dependent system)

Is the SDC structured to support instruction?

Is SDC done in context of the task?

Are reasonable alternative phrasings allowed?

Is instruction given on articulation, volume, etc.?

Speech Recognition Performance

Is the recognition accuracy adequate to support training?

Does the response accuracy of the system approach 99% on phrases critical to the task, e.g., time-constrained interactive events?

Is a Test Mode available?

Is the trainee instructed on how to improve recognition accuracy?

Is the recognition system robust with respect to ambient noise and speaker variabilities?

Is the rejection rate acceptable?

Is the time required for recognition and understanding acceptable?

(Continued)

TABLE E-1. (Continued)

Speech Generation

Is the voice easily understandable?

Is the voice quality (inflection, etc.) acceptable?

Are discriminably different voices available to represent different speakers?

Is the time for speech generation acceptable?

Is the vocabulary and its use consistent with current operational language?

DEVELOPMENT EVALUATION GUIDELINES

1. A repeated cycle of test, evaluate, and revise (TEAR) should be planned at the outset of system development.

2. Guidelines for formal developmental test and evaluation (DTE) are given in proposed OPNAV Instruction (Cordell, et al., 1979).

3. The TEAR plan should be structured hierarchically to address increasingly larger functional units of the training system over time.

4. The TEAR process should be based on explicit evaluation criteria appropriate for each stage of system development and integration.

5. Quantitative tests and evaluation criteria should be generated whenever possible.

6. The final stages of system development and integration must be subjected to the TEAR process. Tests at this stage should use trainees representative of the user population, and should exercise all branches of the system courseware. A group of SMEs is recommended to assist in this final TEAR cycle of the system development.

DISTRIBUTION

Commanding Officer
Naval Training Equipment Center (N-71)
Orlando, FL 32813 40

Defense Technical Information Center
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Alexandria, VA 22310 12

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Prof. Alphonse Chapanis, Director
Communications Research Laboratory
Suites 302 & 303; 7402 York Road
Baltimore, MD 21204

Mr. Leon Lerman
Lockheed Missiles & Space Co.
86-10, Bldg. 182
Sunnyvale, CA 94086

Dr. Carol A. Simpson
Psycho-Linguistic Research Assoc.
2055 Sterling Avenue
Menlo Park, CA 94025

Dr. John Welch
Threshold Technology, Inc.
1829 Underwood Blvd.
Delran, NJ 08033

CDR Charles W. Hutchins
Naval Post Graduate School
(Code 55MP)
Monterey, CA 93940

Dr. Wayne A. Lea
Speech Communications Research Lab.
806 W. Adams Blvd.
Los Angeles, CA 90007

Dr. Robert A. North
Honeywell SRC
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Minneapolis, MN 55413

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and Technology
National Bureau of Standards
Washington, DC 20234

Dr. Jesse Orlansky
Sciences and Technology Division
Institute for Defense Analyses
1801 North Beauregard St.
Alexandria, VA 22311

CDR Joseph Funaro, Code 602
Naval Air Development Center
Human Factors Engineering Branch
Warminster, PA 18974

Douglas Chatfield, Ph.D.
Behavioral Eval. & Training Systems
5517 74th St.
Lubbock, TX 79424

Dr. Donald W. Connolly
US DOT, FAA
NAFEC ANA-230
Atlantic City, NJ 08405

Dr. Thomas P. Moran
Xerox, Palo Alto Research Center
3333 Coyote Hill Road
Palo Alto, CA 94304

Mr. Melvin I. Strieb
3535 NASA, Rd. 1, Apt. 82
Seabrook, TX 77586

Dr. William S. Meisel
Technology Service Corp.
2950 31st Street
Santa Monica, CA 90405

Dr. Mark F. Medress
ITT, Defense Communications Division
9999 Business Park Avenue
San Diego, CA 92131

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Bolt, Beranek & Newman, Inc.
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Dallas, TX 75243

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US Postal Service, R&D Labs
11711 Parklawn Dr.
Rockville, MD 20852

Dr. John Ruth
General Dynamics Corp.
P.O. Box 748
Mail Zone 1352
Fort Worth, TX 76101

Dr. Marshall Farr
Office of Naval Research
800 N. Quincy Street
Arlington, VA 22217

Dr. John D. Fort, Jr.
Code 13
NPRDC
San Diego, CA 92152

Dr. James McMichael
Code 14
NPRDC
San Diego, CA 92152

Mr. Robert Smith
CNO (OP 98)
Washington, DC 20350

Dr. Clyde Brictson
Dunlap & Associates, Inc.
920 Kline St., Suite 203
La Jolla, CA 92037

Mr. P. J. Andrews
SEA 61R2
Naval Sea Systems Command
Room 880, Crystal Plaza 6
Washington, DC 20360

Dr. David Lambert (Code 823)
Naval Ocean System Center
271 Catalina Blvd
San Diego, CA 92152

John Sigona
Dept. of Transportation
DOT/TSC-533
Kendal Square
Cambridge, MA 02142

Mr. John Martins, Jr.
Project Engineer
Naval Underwater Systems Center
New London Laboratory MC 315
New London, CT 06320

Mr. David Hadden
US Army Electronics Command
Advanced Systems Design and Dev. Div.
Chief, Computer Techs & Dev. Team
Ft. Monmouth, NJ 07703

Mr. Lockwood Reed
US Army Avionics R&D Activity
DAVAA-E
Ft. Monmouth, NJ 07703

Dr. Donald W. Connolly
Research Psychologist
Federal Aviation Administration
FAA NAFEC ANA-230 Bldg 3
Atlantic City, NJ 08405

Dr. Bruno Beek
Rome Air Development Center
Griffiss Air Force Base
Rome, NY 13441

LT Jeff Woodard
RADC/IRAA
Griffiss AFB
Rome, NY 13441

Commanding Officer
Navy Fleet Material Support Office
P.O. Box 2010
Attn: Ralph Cleveland, Code 9333
Mechanicsburg, PA 17055

Mr. Leahmond Tyre
Fleet Material Support Office
Code 9333
Mechanicsburg, PA 17055

CDR P. M. Curran
Office of Naval Research
(Code 270)
800 North Quincy Street
Arlington, VA 22217

Mr. Robert Larr
Naval Air Development Center
Code 8143
Warminster, PA 18974

Dr. Christian Skriver
Naval Air Development Center
Code 6021
Warminster, PA 18974

Mr. William E. Gibbons
Naval Air Development Center
Warminster, PA 18974

Mr. Frank R. Previti
Naval Air Development Center
Mail Code 4043
Warminster, PA 18974

Dr. Julie A. Hopson
Naval Air Development Center
Code 6021
Warminster, PA 18974

LCDR Steve Harris
Naval Air Development Center
Code 6021
Warminster, PA 18974

Charles R. Lueck, Jr.
United States Postal Service
Process Control Systems Test Facility
9201 Edgeworth Drive
Washington, DC 20027

Mr. Ben Wallis
Computer Analyst
David Taylor Naval Ship R&D Center
Bethesda, MD 20084

OUSDR&E (R&AT) (E&LS)
CDR Paul R. Chatelier
Washington, DC 20301

Chief of Naval Operations
OP-39T
Washington, DC 20350

Mr. Hal Murray
Naval Air Systems Command
Code 53343B
Building JP-2, Room 610
Washington, DC 20360

Naval Air Systems Command
Code 5313A
Attn: LT Thomas M. Mitchell
Washington, DC 20361

Commander
Naval Air Systems Command
Air 340F
Washington, DC 20361

Commander
Naval Air Systems Command
AIR 413F
Washington, DC 20361

Mr. Ernest E. Poor
Naval Air Systems Command
Air 413B
Room 336
Washington, DC 20361

F. Leuking
Naval Air Systems Command
AIR-360A
JP-1, Room 612
Washington, DC 20361

CDR Richard S. Gibson
Bureau of Medicine and Surgery
Head, Aerospace Psychology Branch
Code 3C13
Washington, DC 02372

Dr. Sam Schiflett
Naval Air Test Center
SY 721
Patuxent River, MD 20670

Director, National Security Agency
9800 Savage Road
Attn: T. W. Page, R54, FANX II
Ft. George G. Meade, MD 20755

Dr. John F. Boehm
Director, National Security Agency
9800 Savage Road
Attn: R-542, Boehm
Ft. George G. Meade, MD 20755

Mr. Harold C. Glass
US Postal Lab
11711 Parklawn Drive
Rockville, MD 20852

Mr. John T. Masterson
US Postal Lab
11711 Parklawn Drive
Rockville, MD 20852

Abraham Tersoff Gen. Manager
US Postal Service Res. Center
11711 Parklawn Drive
Rockville, MD 20852

Dr. Tice De Young
US Army Engineer Topographic Laboratories Research Institute
Ft. Belvoir, VA 22060

Defense Adv. Research Projects Agency
Information Processing Tech. Office
1400 Wilson Boulevard
Arlington, VA 22209

Defense Adv. Research Projects Agency
Cybernetics Technology Office
1400 Wilson Boulevard
Arlington, VA 22209

Defense Adv. Research Projects Agency
Infor. Processing Techniques Office
1400 Wilson Boulevard
Arlington, VA 22209

Chief of Naval Research
Code 458
800 N. Quincy St.
Arlington, VA 22217

Office of Naval Research (Code 221)
Dir., Electromagnetic Technology
800 N. Quincy St.
Arlington, VA 22217

Mr. Jerry Malecki
Office of Naval Research
Code 455
800 N. Quincy St.
Arlington, VA 22217

Mr. Gordon D. Goldstein
Office of Naval Research
Code 437
800 N. Quincy St.
Arlington, VA 22217

Mr. J. Trimble
Office of Naval Research
Code 240
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Arlington, VA 22217

Dr. Henry M. Halff
Office of Naval Research
Code 458
Arlington, VA 22217

Dr. Henry J. Dehaan
US Army Research Institute
5001 Eisenhower Avenue
Alexandria, VA 22333

Charles Hartz
FLECOMTRACENLANT
Code 02A
Virginia Beach, VA 23416

Mr. Joe Dickinson
US Army Applied Tech. Lab
Ft. Eustis, VA 23662

CAPT Leslie K. Scofield
Directorate of Training
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Ft. Gordon, GA 30905

Dr. James D. Mosko
Naval Aerospace Medical Res. Lab.
Acoustical Sciences Division
Code L348
Pensacola, FL 32508

MAJ Neal Morgan (LGY)
Air Force Logistics Mgmt Center
Bldg. 205
Gunter AFB, AL 36114

Dr. Michael G. Sanders
US Army Res. Inst. Field Unit
P.O. Box 476
Ft. Rucker, AL 36362

CWO2 Ray Priest
Naval Air Tech. Training Center
Code 7411
NAS Memphis (85)
Millington, TN 38054

Lt. Col. Robert O'Donnell
6570 ARML-HEA
Wright-Patterson AFB
Dayton, OH 45322

Mr. Eric Werkowitz
AFFDL/FGR
Wright Patterson AFB, OH 45433

ASD/AXA
Attn: N. R. Vivians
Wright-Patterson AFB, OH 45433

CAPT Barry P. McFarland
US Air Force
ASD/ENECH
Wright-Patterson AFB, OH 45433

Mr. Don F. McKechnie
Research Psychologist
AFAMRL/HEF
Wright-Patterson AFB, OH 45433

CAPT Ronald J. Marine
US Air Force
ASD/AER-EX
Wright-Patterson AFB, OH 45433

Mr. John Courtright
AFAMRL/HEG
Wright-Patterson AFB, OH 45433

Mr. Don Monk
AMRL/HED
Wright-Patterson AFB, OH 45433

Mr. Thomas J. Moore
AFAMRL/BBA
Wright-Patterson AFB, OH 45433

CAPT Vince Mortimer
AFAMRL/BBM
Wright-Patterson AFB, OH 45433

Noel P. Schwartz
AFHRL/ASM
Advanced Systems Division
Wright-Patterson AFB, OH 45433

Mr. Timothy Theis
ASD/RWR
Building 20, Aero. B
Wright-Patterson AFB, OH 45433

Chief of Naval Education & Training
Liaison Office
Human Resource Laboratory
Flying Training Division
Williams AFB, AZ 85224

Robert F. Lawson, CDR, USN (Ret)
Naval Applications Engineer
ONR Scientific Department
1030 E. Green Street
Pasadena, CA 91106

Dr. Keith Bromley
Naval Ocean Systems Center
Code 8111
San Diego, CA 92152

Mr. Warren Lewis
Naval Ocean Systems Center
Human Engineering Branch
Code 8231
San Diego, CA 92152

Mr. Harry A. Whitted
Code 8235
Naval Ocean Systems Center
271 Catalina Boulevard
San Diego, CA 92152

Dr. Robert A. Wisher
Navy Personnel Research and
Development Center
Code P309
San Diego, CA 92152

Mr. Melvyn C. Moy
Navy Personnel Res. & Dev. Center
Information & Decision Processes
Code 305
San Diego, CA 92152

John Silva
Naval Ocean Systems Center
Code 823
San Diego, CA 92152

Mr. Gary Poock
Naval PG School
Code 55PK
Monterey, CA 93940

Mr. Clayton R. Coler
Research Scientist
NASA Ames Research Center
Mail Stop 239-2
Moffett Field, CA 94035

Hallie M. Funkhouser
Technical Assistant
NASA, Ames Research Center
Mail Stop 293-3
Moffett Field, CA 94035

Kinga M. Perlacki
NASA, Ames Research Center
Mail Stop 239-2
Moffett Field, CA 94035

Dr. Edward Huff
Chief, Helicopter Human Factors Ofc
Mail Stop 239-21
NASA, Ames Research Center
Moffett Field, CA 94035

Dr. Robert P. Plummber
Asst. Prof., University of Utah
NASA, Ames Research Center
Mail Stop 239-2
Moffett Field, CA 94035

Mr. Robert H. Wright
Research Psychologist
Army Research Inst. Field Unit
P.O. Box 476
Ft. Rucker, AL 56362

Commander
Naval Air Systems Command
Air 413G
Washington, DC 20361

Mr. Ray Satterfield
Photographer
Naval Air Development Center
Warminster, PA 18974

National Aviation Facilities
Experimental Center
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OP-593B
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Naval Weapons Center
Code 3154
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Commanding Officer
Fleet Anti-Submarine Warfare
Training Center, Pacific
Attn: Code 001
San Diego, CA 92147

Commander
Naval Air Test Center
CT 176
Patuxent River, MD 20670

Dr. J. D. Fletcher
Defense Adv. Research
Projects Agency (CTO)
1400 Wilson Boulevard
Arlington, VA 22209

Commanding Officer
Naval Air Technical Training Center
Code 104, Building S-54
NAS Memphis (85)
Millington, TN 38054

Mr. Walt Primas
Chief of Naval Operations
OP-39T
Washington, DC 20350

Chief of Naval Operations
OP-987H
Attn: Dr. R.G. Smith
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US Army Field Artillery School
Counterfire Department
Attn: Eugene C. Rogers
Ft. Sill, OK 73503

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US Army Human Eng. Laboratory
Attn: DRXHE-HE (KEESEE)
Aberdeen Proving Ground, MD 21005

USAHEL/USAAVNC
Attn: DRXHF-FR (Dr. Hoffmann)
P.O. Box 476
Ft. Rucker, AL 36362

ASD/ENESS
Attn: R.B. Kuhnen
Wright Patterson AFB, OH 45433

Air Force Human Resources Lab
AFHRL/LR
Logistics Research Division
Wright Patterson AFB, OH 45433

LT Dave Cooper
AFHRL/OTT
Wright Patterson AFB, OH 45433

US Air Force Human Resources Lab
AFHRL-IT (Dr. Rockway)
Technical Training Division
Loury AFB, CO 80230

US Air Force Human Resources Lab
TSZ
Brooks AFB, TX 78235

ASD/ENETC
Mr. R.G. Cameron
Wright Patterson AFB, OH 45433

Headquarters 34 Tactical Airlift
Training Group/TTDI
Little Rock AFB, AL 72076

Headquarters
Air Training Command, XPTI
Attn: Mr. Goldman
Randolph AFB, TX 78148

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Library (TSLD)
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Director
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Mr. Harold A. Kottmann
ASD/YWE
Wright Patterson AFB, OH 45433

Aeronautical Systems Div.
USAF, ASD/YWB (R. Coward)
Wright-Patterson AFB
Dayton, OH 45433

CDR Charles Theisen
Lauren Ridge
R.D. #2, Box 143-8A
New Hope, PA 18938

Chief
ARI Field Unit
P. O. Box 476
Ft. Rucker, AL 36362

DATE
ILME